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Titulación :

INGENIERO INDUSTRIAL

Título del proyecto:

DEVELOPMENT OF A MEASUREMENT BOX TO MEASURE THE 3D WIND SPEED IN AN URBAN ENVIRONMENT

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ABSTRACT

The present work aims to build a low-cost three-dimensional anemometer to measure the wind speed and direction in an urban environment.

To begin with, some research on basic principles in scientific literature and also in patent database was done.

Secondly, a market study was carried out and two propeller anemometers were purchased. A hi-tech ultrasonic sensor was also purchased to gather accurate measurements and to serve as input for the calibration of the low-cost anemometer.

The propeller anemometers were then calibrated in a wind tunnel and some unexpected measuring errors became visible. Their accuracy was not as high as it had been anticipated in the datasheets. This resulted in a collaboration with the manufacturers to test and improve their products. Some more tests were carried out and concluded with great results.

Then, the three-dimensional sensor was assembled using the two propeller anemometers and it was subsequently cross-checked with an ultrasonic anemometer in a roof of the Erasmushogeschool Brussel.

Finally, a program was created to collect the data from the ultrasonic sensor and store the information in a file.

To sum up, this project meets all the desired goals: it works autonomously, collects the data, and is movable. In addition, some other technical statements were concluded: at low wind speeds, the propeller anemometers also had a low resolution and measurements corresponding to the horizontal plane were more accurate than those for the vertical component of the wind.

One of the most significant results of this project is the fact that this work allowed helping the manufacturers to improve the propeller anemometers; their accuracy was reduced by more than 5%. In addition, the development of a program to log the wind speed data from the ultrasonic anemometer eliminated the need for an expensive data logger.

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Chapter 1. INTRODUCTION

1 GENERAL INTRODUCTION

The 3D anemometer development is part of research carried out in the Erasmushogeschool Brussels (EhB) by different research groups.

On the one hand, there is the mechanics group which is interested in the use of wind turbines in an urban environment. The vertical component of the wind is required due to the possible occurrence of an upstream in built-up environments. This group is headed by Dr.Mark Runacres.

On the other hand, there is the Electronics and ICT group which has an interest in a 3D anemometer to complete its sound studies, to account for the influence of wind speed on acoustics. This group is headed by Dr. Abdellah Touhafi.

The purpose of this thesis is to assemble a simple and inexpensive three-dimensional anemometer sensor in order to measure the wind speed and direction in an urban environment. By mounting two integrated propeller anemometers, calibrated and checked, 3D measurements can be carried out and data can be collected.

This thesis also involves the purchase of a hi-tech ultrasonic anemometer to perform precise measurements that serve as input for the calibration of the low-cost anemometer.

This project produced the following results:

- The sensor fulfils the desired requirements: it works autonomously, collects the data and is movable.

- The accuracy of the propeller anemometers purchased was reduced by more than 5%.

- Measurements corresponding to the horizontal plane are more accurate than those for the vertical component of the wind.

- At low wind speeds, the propeller anemometer also has a low resolution.

- The development of a program to log the wind speed data from the ultrasonic anemometer eliminates the need for an expensive data logger.

1.1 DESCRIPTION OF THE THESIS

CHAPTER 1

This chapter presents the General Introduction and describes the aims and the context in which this project is developed.

CHAPTER 2

This chapter points out the importance of an anemometer and describes the fundamentals of all kinds of wind sensors.

CHAPTER 3

This chapter consists of a market study covering the diverse wind sensors and emphasizing their main features.

CHAPTER 4

This chapter includes the ultrasonic anemometer purchase after comparing the main features between several ultrasonic models.

CHAPTER 5

This chapter involves the comparison of some low-cost sensors features and the later purchase decision.

CHAPTER 6

This chapter describes the process of calibration carried out to know the exact measuring error the purchased anemometers have.

CHAPTER 7

This chapter shows the way the three dimensional low cost anemometer is assembled.

CHAPTER 8

This chapter describes the process of how the different components of the wind speed are measured by the low-cost anemometer.

CHAPTER 9

This chapter compares the low cost anemometer and the reference, the ultrasonic anemometer.

CHAPTER 10

This chapter consists of the explanation of the different ways data can be collected from the purchased anemometers.

CHAPTER 11

This chapter contains the final conclusions and the corresponding recommendations.

CHAPTER 12

This chapter includes the bibliography used to write this thesis.

CHAPTER 13

This appendix consists of the datasheet of the propeller anemometer and the manual of the ultrasonic sensor purchased for this project.

Chapter 2. THE BASICS

1 THE IMPORTANCE OF A 3D ANEMOMETER

An anemometer is an apparatus for measuring the force of air or the speed of wind and usually its direction. This term is derived from *anemos*, which means wind in Greek. Depending on the mechanisms, there is a diversity of anemometer types, explained in the next section. **[10]**

The development of an anemometer is critical to the installation of a wind turbine. A wind turbine needs to be oriented to the wind direction. The power generated is proportional to wind speed which passes across the turbine, but cubed, so a wrong position would mean losing a lot of power and, in an economical point of view, losing money. **[1]**

Thus, the wind turbine installed in the EhB campus will have to be oriented to the predominant wind direction and the installation of an anemometer is highly recommended before considering any installation of this type.

A typical big wind turbine located in a landscape and made by a common manufacturer such as Gamesa has two 2D anemometers, wind vane and ultrasonic anemometer, while the purpose of this project is a 3D anemometer. **[2]**

This may be a waste of money because a big wind turbine would produce much more power and consequently much more money than a wind turbine installed in the EhB campus. However, there is one main reason to why 3 dimensions are required here. That reason is the urban environment.

Unlike the "almost laminar" airflow in landscape, on-site wind farms, the wind regime in urban environment is highly affected. These areas act as a brake to wind, creating a highly dynamic and turbulent flow which includes a strong vertical component. This vertical speed is often disregarded when assessing the wind energy potential. **[1][30]**

Nowadays, there is a lack of understanding about wind flows in this environment: they are subject to frequent changes in wind speed and direction. In addition, wind turbulence is high because of the obstacles of the urban environment. This project attempts to create a wind sensor so that this effect can be studied.

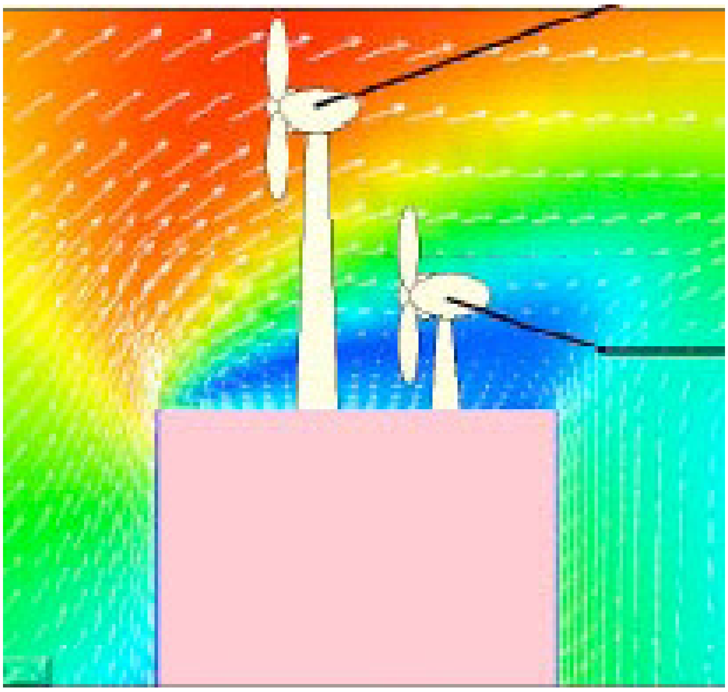


Figure 1: Simulation of wind over a building **[33]**

2 TYPES OF ANEMOMETERS

2.1 Rotating Vane Anemometer

Rotating vane anemometers are simple devices which provide fast, reliable and accurate readings of air velocity, but not wind direction measurements. They are handheld and digital, usually with a small fan, a LCD display and a data-logger attached. This tool is very useful when a quick measurement is needed, for example, grilles, ducts, or diffusers… **[3]**

As it does not provide the direction from which the wind blows, rotating vane anemometers should be placed facing the desired direction. It should be held in the hand and the person looking at the display directly.

Figure 2: Kestrel 4000 Pocket Weather Tracker **[25]**

When the wind blows, the fan blades and a small generator connected to them start spinning. The faster the rotor blades turn, the quicker the generator spins and the higher the electric current it will produce. Precisely calibrated, this device will provide a mathematical relationship between the electric current and the wind speed. **[11]**

However, this generator is directly connected to an electronic circuit, so there is no need to measure the current because the data appears automatically in the digital display.

Advantages:

The core advantage of this device is its size and mobility. It is quite small and handheld. It can be kept on hand in various places and situations and provide reliable air velocity measurements in harsh environments. Moreover, its low price, convenient size, and considerable accuracy are particularly attractive features. The rotating vane anemometers can measure wind speed in all directions needed just pointing it into the wind flow.

Disadvantages:

On the other hand, it is not typically considered for wind measurement research with the exception of some practical situations where accuracy is not a priority. Furthermore, the range of wind from where this tool can gather information is significantly reduced (0-30m/s) compared to other types of anemometer. The rotating vane anemometer is a mechanical tool, so the moving parts can sometimes become defective. **[3]**

2.2 Cup Anemometer

This is the most common and oldest style anemometer, invented in 1846 by Dr. Thomas Romney Robinson of Armagh University. The rotating cup anemometer consists of three or four semi-spherical or conical cups attached to arms of a hub that is allowed to revolve freely around a normally vertical shaft. **[12]**

As the current of air blows against the cups, the anemometer starts rotating. This movement is due to the wind forces pushing the cups and creating some moments around the vertical shaft, the center of rotation.

The frequency of rotation can be translated as wind speed. This is possible because, as it will be demonstrated next, the anemometer rotates at a speed which is proportional to the wind speed. An example with a three cup anemometer is showed next:

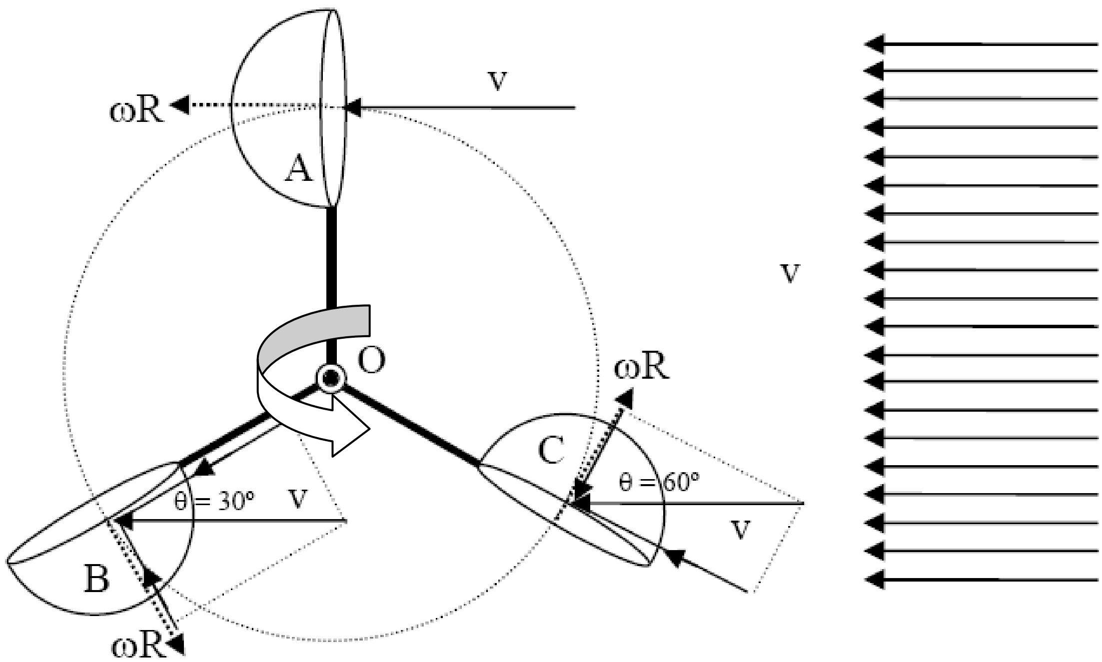


***Figure 3: Velocities and torques in a three cup anemometer* [28]**

v: wind speed

ρ: air density

C_{dv} , C_{dx}: drag coefficients for the concave and convex faces (typical values: 1,4 and 0,4 respectively)

A: frontal area

R: rotor radius

ω: rotating speed

M_R: resistant torque

$$\sum M_O = M_A - M_B - M_C - M_R$$

$$\sum M_O = \frac{1}{2} C_{dv}\rho(v-\omega R)^2 A \cdot R - \frac{1}{2} C_{dX}\rho(vsen30° + \omega R)^2 A \cdot R - \frac{1}{2} C_{dX}\rho(vcos60° + \omega R)^2 A \cdot R - M_R$$

Supposing null the resistant torque and steady state, when the rotating speed is constant there is a torque balance ($\sum M = 0$), and the expression can be simplified to:

$$\sum M_O = \frac{1}{2}\rho A \cdot R\left[v^2\left(C_{dv} - \frac{1}{2}C_{dx}\right) - v\big(2\omega R(C_{dv} + C_{dx})\big) + \omega^2 R^2 (C_{dv} - 2C_{dx})\right] = 0$$

Thus, a second grade equation is obtained:

$$\left[v^2\left(C_{dv} - \frac{1}{2}C_{dx}\right) - v\big(2\omega R(C_{dv} + C_{dx})\big) + \omega^2 R^2 (C_{dv} - 2C_{dx})\right] = 0$$

The solution is: $v = \omega R \frac{2(C_{dv}+C_{dx}) \pm 3\sqrt{2}\sqrt{(C_{dv} \cdot C_{dx})}}{(2C_{dv} - C_{dx})}$; $\boldsymbol{v = k \cdot \omega}$ **[28]**

What was desired has been demonstrated; the linear sensitivity of the cup anemometer to wind speed. Moreover, it shows how this constant, *k,* does not depend on the size of the anemometer, only on the drag coefficients of the cups.

Another way to see the same aspect is: $\boldsymbol{v = k' \cdot \omega R = k' \cdot v_T}$

This means that the wind speed is proportional to the tangential velocity *(v_T)* of a point situated in the center of a cup. This new constant, *k'*, is usually a value between 2 and 3, depending again on the drag coefficients. These constants and so the relationship between the wind speed and the rotation frequency is determined by calibration. **[7]**

However, the rotating speed cannot directly be known unless a display is available to show it. To that end, some anemometers offer different solutions depending on the output signal. This is valid for all types of anemometers, but the only difference is the nature of the signal: analog or digital.

Rotation speed can be measured by a number of different mechanisms, but tiny magnets are often used. They are mounted on the cups and each time the anemometer completes a full rotation the magnet is detected by what is called a 'reed switch'. Then, when the magnet is nearby, the reed switch closes and triggers an output electric pulse, before opening again when the magnet goes away. Frequency is then converted into wind speed as it will be shown in the market study. **[4]**

If the anemometer has a frequency-to- voltage/current converter, the main outputs will be voltage or current signals, which are also proportional to wind speed. Finally, the shaft can also contain an encoder in order to obtain a digital output.

***Figure 4: Cup anemometer* [26]**

Advantages:

The cup anemometer is an easy-to-use device and it is commonly used nowadays. The reason why the cup anemometer is and has been so successful is the simple construction, the low price, and other distinctive characteristics.

Disadvantages:

This anemometer is a mechanical tool so its moving parts will wear out. It also has an effect called “overspeeding”. This means that in fluctuating winds, the mean indication will be higher than the true average wind speed. Moreover, it reacts slowly to sudden changes in wind. **[29]**

2.3 Propeller Anemometer

Propeller anemometers are also called wind vane anemometers, windmill anemometers or simply helicoid propeller anemometers. They normally consist of a propeller, with three or four blades, which rotate on a horizontal shaft. This axis must be parallel to air flow, so when the wind varies in direction the wind sensor is turned into the wind flow.

Following these changes is the purpose of the vane. It is used in conjunction with the propeller and they are both in the main body, one in each side of the anemometer.

Figure 5: R M Wind Monitor Model 05103 **[5]**

The propeller works in a similar way to how the rotating vane anemometer does. The blades are connected to a small generator and when the air flow blows, they rotate. The propeller rotation produces an AC sine wave voltage signal with frequency directly proportional to wind speed. Measuring its frequency, the velocity of the wind will be known. **[6]**

There is one change: how the vane works and how the signal is processed into a specific wind direction. This wind direction sensor has a precise potentiometer which is excited by a determined voltage signal. Depending on the position of the vane the output voltage will change, hereby measuring this output voltage, the vane angle will be known and consequently so will the wind direction.

Advantages:

Propeller anemometers are simple and compact. They do not have a big size, which makes them hand-held and easy-to-use. Their response to gusts is better than cup anemometers and it is clear that are reasonable sensors for measuring turbulence. In addition, their wind range is the largest, far away from other sensors ranges.

Disadvantages:

This tool is also mechanical so it has moving parts which can wear out. Another disadvantage is the necessity of being turned into the flow direction. However, the most outstanding one is the inability in turbulent wind to track sudden wind changes. Hence, this effect can place the propeller off the wind direction resulting in a lower wind speed measurement. **[29]**

2.4 Hot Wire Anemometer

Hot wire anemometers have been extensively used for a long time as a research tool in fluid mechanics. One of the main advantages of these devices is their high-frequency response. They are capable of reading instantaneous values of velocity up to very high frequencies. Thus, it is extremely useful in measuring the turbulent fluctuations of the fluid flow.

Hot wire anemometers operate on the principle of heat transfer. They normally measure fluid velocity taking into account the amount of heat extracted by the air flow from the heated wire. This fine filament is often heated to a constant and fixed temperature (CTA, Constant Temperature Anemometer), though some devices heated by a constant current (CCA) or by a constant voltage (CCV) are also available. **[7][13]**

The current then passes through an electrical resistance and the energy is converted to heat. As the fluid flows over the wire, it is cooled and an amount of heat is lost due to convection.

In order to maintain the filament at a constant temperature, the current increases. As this current is a function of the fluid velocity which passes over the wire, measuring its change, the velocity of the fluid will be easily known.

In case the anemometer is a constant current device, the heat loss can be obtained by measuring the change in wire temperature. As the electrical resistance of most metals is dependent upon the temperature of the metal, the value of the resistance will help to know definitely the flow velocity. **[13]**

Figure 6: Hot wire anemometer **[15]**

This type of anemometer mainly consists of small diameter probes that allow doing measurements in tight spaces and hard to reach areas. These sensors have such an electrical resistance that it can be easily heated with low current and voltage levels. The wires are mainly made of tungsten, platinum and platinum-iridium alloy.

Advantages:

This anemometer stands out because of its capability to make measurements in tough environments such as pipes or tubes flows. In addition, it has a good spatial resolution because it can measure the flow in a precise location. For these reasons, this tool is perfect for ducts. It also reacts quickly to sudden changes in air flows.

Disadvantages:

Like rotating vane anemometers, hot-wire sensors have the lowest measuring range on the market. Moreover, the accuracy of the measurements is quite poor (±3% of error) and it is very sensitive in orientation. Other disadvantages are the high-priced tungsten wire and the limitation of the cable length joining the display with the probe. **[13]**

2.5 Ultrasonic Anemometer

Sonic anemometers have been primarily used in research applications. The penetration into the general meteorology market was mainly impeded by their relatively high cost compared to mechanical sensors. However, nowadays it is a clear alternative to the cup and vane anemometers at about a bit higher price. **[31]**

Sound travels by making air molecules move back and forth. It is obvious that the speed at which sound travels depends directly on the speed of the wind and it will be affected by how strong the wind is. An ultrasonic anemometer measures wind speed and direction using ultrasonic (high-frequency, typically 100 kHz) sound waves. It uses the propagation speed of sound between points of known separation to determine the speed and direction of the air flow.

An ultrasonic anemometer usually consists of two (on rare occasions three) pair of transducers (piezoelectric devices that can emit and receive sound beams) mounted at right angles facing one another. The anemometer stands in the way of the wind and each transmitter emits high-frequency sound waves into the wind towards its respective receiver successively.

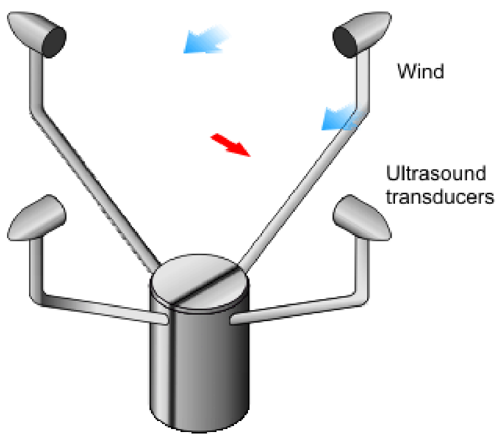


***Figure 7 : Wind wave (blue) and Sound wave (red) in an ultrasonic anemometer* [16]**

Depending whether the wind is behind or in front of the sound wave, the sound beam will cross the gap faster or slower. Some electronic circuits measure the time of flight (TOF) of the sonic impulse from the transmitter to the receiver. Then, their functions are exchanged and a second beam is emitted in the opposite way.

By calculating the time the sound beam lasts to cross back and forward across the gap and measuring the difference in speeds of the waves, the *wind speed* will be known. Discovering the difference in angle between the wind flow and the sound beam, *wind direction* will be also determined. **[31]**

Advantages:

This tool does not have moving parts so there is much less maintenance. Its chief attributes are the resolution and the accuracy. It can handle wind gusts and highly variable values.

Furthermore, it is a fast device that can take thousands of measurements per second and its reduced threshold allows tracking really low winds. This kind of anemometer is ideally suited to measure turbulent air flows. **[14]**

Disadvantages:

The most significant disadvantage of using sonic anemometry is the inherent cost, as well as its complexity. There are also some other environment factors like rain that can prevent it from operating.

2.6 Laser Anemometer

The first laser Doppler anemometer was built in 1964, when Yeh and Cummis first use the Doppler shift of laser light to measure the velocity of a fluid. A large amount of research has been performed over the years with many changes being made to the original design. This anemometer is now considered to be a new wind-sensing tool due to modern advancement.

An eye-safe infrared beam is generated to a fixed point. This serves as the reference beam. This beam, after contacting aerosols (particles suspended in the atmosphere such as dust, dirt or water droplets), is partly backscattered into a receiver. Thus, the new reflected beam is called the measurement beam. **[8][32]**

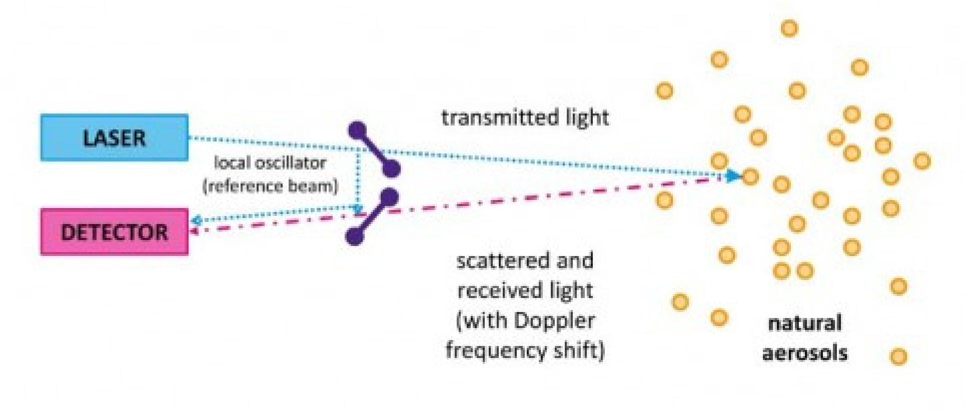


Figure 8: How measurements are made by a laser anemometer **[8]**

The motion of the particles through the beam causes a difference in the light's frequency between both beams. This change in frequency is directly related to Doppler effect: "*the relative motion of an observer from light waves, creates a difference between frequencies at which light waves leave a source and that at which they reach the observer*". Therefore, measuring the frequency shift, the velocity of its cause, and wind speed in this case, can be precisely measured. **[8]**

Note: this is possible assuming that very small particles move with the air at its same speed.

This staring working mode, in which the beam is generated in only one direction, can be easily turned into a conical mode with the help of only a wedge. This tool makes the beam drive in an oblique direction (one angle to the vertical axis), and consequently, if it rotates at a constant speed, the scanning mode is conical.

As a result, turning the beam allows intercepting the wind at different angles, so a disc of air provides enough measurements to know the wind velocity vector.

By adjusting the lens, the beam can be focused to the desired height up to 200 meters. In order to obtain information related specifically to turbulence, scanning at each height should be made during several seconds.

Figure 9: ZephIR laser anemometer **[8]**

Advantages:

This hi-tech device provides wind speed and direction up to 200 meters. This means that a mast is not needed. With a couple of mere adjustments, wind data can be obtained at a different height. This device is also highly portable and there is no need to install it in the top of a building.

This sensor is not placed in the air flow measured; therefore, it does not disturb the flow as other anemometers do. Finally, the Doppler laser anemometer can obtain each 3D measurement in milliseconds, which provides a vast amount of high-accurate information. **[32]**

Disadvantages:

These systems are not yet in widespread use for wind energy applications. They are not worthwhile for small isolated turbines and there are very few manufacturers. As a result, the price is the primary drawback. They are usually mounted into the ground, and as a result, it makes them vulnerable to issues such as thefts and damage.

Chapter 3. MARKET STUDY

In this chapter a market study is carried out covering the main features (measuring range, temperature, accuracy, output signal, materials) of the diverse types of solutions which are currently in the market.

All the information in this section is collected from data sheets of the different anemometers in the market. The diversity of wind sensors is so huge that statements referred to a particular kind of anemometer cannot be written. Hence, data sheets will be referenced at the beginning of each different anemometer in order not to point them out in each paragraph.

This study market presents the different features which helped us to choose an appropriate low-cost solution. It is divided in one, two or three-dimensional anemometers and finally one table compares all wind sensors.

1 1D ANEMOMETER

1.1. Rotating Vane Anemometer

The data sheets used in this section are: **[36][40][41][42]**

Measuring range

It typically covers from 0 m/s to 30 m/s, and the common starting threshold is 0.25 m/s.

Another useful feature is the possibility of measuring volume flow. Multiplying the wind speed which goes through the propeller and the area of this fan, which the flow is perpendicular to, the volumetric flow rate can be calculated. According to manufacturers it has an approximated range from 0.002 to 3000m^3/s.

Operating Temperature

According to data sheets vane anemometers usually have the following temperature range: -10ºC…60ºC.

These devices are not suitable to be used in so extreme conditions as the other ones so they don't actually need a heating unit.

Accuracy

Some manufacturers assure that this kind of anemometers have a general ±1% error or ±0.02m/s if the wind speed is below 1m/s, which is even greater.

Output

Data can be recalled and downloaded via an analog output or through USB ports or the RS-232 interface directly into a PC.

Materials

Materials are not emphasized by vane anemometer manufacturers. However, the main body is usually made of plastic and the propeller is plastic or rugged metal.

Figura 10: Kestrel 4500 **[17]**

Price

The anemometers which have the propeller in the top of the main body are the cheapest ones in the market. They cost between $30 the most simple one up to $640.

On the other hand, anemometers which have a probe connected to the main body are more expensive: $200 to $815.

1.2. Hot Wire Anemometer

The data sheets used in this section are: **[18] [43][44][45]**

***Figure 11: HWA4204HA Digital Hot Wire Anemometer* [18]**

Measuring range

Hot wire anemometers have the lowest range in all over the market. They can only reach 30 m/s and because of the probe they have, that makes easy to access through reduced holes, they are used in small ducts.

Starting threshold

Manufacturing companies estimate that these anemometers do not usually properly measure wind speed below 0.2 m/s.

Operating Temperature

Data sheets do not show information related to operating temperature.

Accuracy

In spite of the fact that their range is quite reduced, their measurement error is, according to datasheets, one of the biggest ones: ±3% of reading.

Output

Data can be read in a LCD display but data acquisition system and data loggers are needed to store values. Apart from that, datasheets normally do not mention RS-232 serial output.

Materials

As it was written before, they all have a LCD display. The case and keypad are generally made of plastic, while the telescoping probe, which is the sensor that measures the wind, is usually stainless steel.

Price

Hot wire anemometers are not so expensive: On the word of manufacturers, they cost between $300 and $600. The most expensive element is obviously the tungsten wire.

2 2D ANEMOMETER

2.1. Cup Anemometer

The data sheets used in this section are: **[19] [46] [47] [48]**

Figure 12: Anemometer INA-10A **[19]**

Measuring range

In line with manufacturers assessments, the wind range in which this kind of devices work correctly is from 0 to 60-70 m/s

Starting threshold

This type of anemometer measures correctly all wind speeds over 0.5-1 m/s, depending on the manufacturer.

Operating Temperature

The range of temperature in which, according to datasheets, cup anemometers work properly is -35ºC…60ºC. Moreover, some of them can be delivered with a heating unit that allows to work in extreme conditions (artic, off-shore, freeze).

Accuracy

Lower wind speed measurements are more accurate than higher ones. As stated by manufacturers, under 15 m/s they have a tolerance of ±0.2m/s, however, higher wind speed measurements might have a ±2% error.

Output

There are basically 3 different analog possibilities: frequency, voltage or current.

A pulse is induced for each revolution and frequency output is proportional to wind speed.

$$U\,(\frac{m}{s}) = A_0 + B_0 \cdot f(Hz)$$

A_0 and B_0 are approximated values which depend of each anemometer. These values must only be obtained after calibrating it. Thus, A_0 is the offset.

This formula is also used in voltage and current outputs.

$$U\left(\frac{m}{s}\right) = A_0 + B_0 \cdot \mathrm{V}(V)$$

$$U\ (\frac{m}{s}) = A_0 + B_0 \cdot I(mA)$$

Materials

They are made of corrosion resistant materials. On the one hand, the main body is usually made of stainless brass, aluminium, steel or just plastic. On the other hand, the ball bearings are typically made of stainless steel or plastic.

Price

A cup anemometer may cost, on the word of manufacturers, between $250 and up to $1250

2.2.- Propeller Anemometer

The data sheets used in this section are: **[20] [21] [49]**

Measuring range

This type of device has a wider measurement range. According to datasheets it goes from 0m/s up to 100m/s, while the vane's range covers 360º.

Starting threshold

The threshold of the propeller is 1m/s, while the vane is 1.1m/s, as stated by manufacturing companies.

Operating Temperature

The working temperature of a propeller vane is guaranteed by manufacturers to be in the following range: from -50ºC to 50ºC.

Accuracy

Corresponding datasheets assure that their tolerance is ±0.3m/s for the propeller and ±3 degrees for the vane.

Output

Data cannot be often collected by a digital output in this case. However, analog outputs allow to collect the data. Firstly, the propeller gives the user an AC sine wave voltage signal, where frequency is proportional to wind speed.

Secondly, the vane gives the user a DC voltage signal using a potentiometer, from where someone can obtain exactly the wind direction.

Materials

Both core parts of the anemometer, the propeller and the vane, are normally made of stainless steel and they are sometimes anodized with aluminium.

Price

On the one hand, according to the market, a propeller vane may cost between $315 and $1700. It depends on the resolution of the diverse devices.

Figure 13: Rainwise Windlog **[20]**

On the other hand, R M Young Company assures its 3D anemometer cost around $2500 depending on the different models and features. However, with three propellers help a 3D anemometer can be built and it costs $500 each propeller.

Figure 14: 3D propeller anemometer **[21]**

2.3. Ultrasonic Anemometer

The data sheets used in this section are: **[22][23] [50][51]**

Measuring range

The ultrasonic anemometer does not have, on the word of manufacturing companies, a range as wide as the previous anemometers It is quite similar to the range of a cup anemometer: 0 to 70m/s and, its wind direction range is always 360 degrees, without a dead band.

Starting threshold

This is one of the strong features of an ultrasonic anemometer. Its threshold is just 0.01 m/s, according to datasheets, which is a hundredth part of a simple propeller anemometer threshold.

Operating Temperature

An ultrasonic anemometer is, in accordance with manufacturers, prepared to work between -40ºC and 70ºC.

Accuracy

In this case, according to manufacturing companies there are three different tolerances depending on the wind speed:

0..5 m/s	±0.1 m/s
5..30 m/s	±2% of reading
>30 m/s	±3% of reading

Moreover, its wind direction accuracy is said to be ±2º.

Output

Digital and analog outputs are available. Digital ones offer RS232/RS422/RS485/NMEA interfaces while analog ones can be voltage or current signal.

Furthermore, data can be displayed on a PC with some graphic software provided.

Materials

Unlike propeller and cup anemometers, an ultrasonic anemometer does not have mechanical or moving parts and it consists of an only compact body. It usually has stainless steel and anodized aluminium components.

Price

In this section two different cases must be distinguished:

First of all, 2D ultrasonic anemometers are cheaper and their price goes from \$1440 to \$2027, depending on the company producers.

Figure 15: 2D ultrasonic anemometer RM Young 85004 **[22]**

Secondly, 3D ultrasonic anemometers are more expensive and can reach at an amount of GBP £14,355 (16700€) **[9]**

Figure 16: 3D Ultrasonic Anemometer RM Young 81000 **[23]**

3 3D ANEMOMETER

3.1. Laser Anemometer

The data sheet used in this section is: **[8]**

It is not a new-technology device, because it was patented some decades ago, but its uses and features have really increased throughout the years.

Nowadays, it can be considered as a quite new wind-sensing tool. Far from the common cup and vane anemometers, it can measure horizontal and vertical wind speeds, wind direction (3D) and also turbulence.

From now on, all the information given will be referred to *ZephIR*, a Doppler laser anemometer from *Natural Power*, as there are not other laser solutions in the market.

Figure 17: ZephIR Laser Anemometer **[8]**

Measuring range

This device has a typical wind speed range: 0 to 70m/s. However, a note has to be made here. According to *Natural Power* [8] it can obtain measurements from 11 meters up to 200 meters high, which is perfect to wind turbines because it can be easily installed in the ground. What is more, there is no necessity of installing it in a higher level or a mast.

Starting threshold

The minimum wind speed this anemometer is able to collect is on the word of manufacturers 2m/s.

Operating Temperature

The operating temperature conditions of a laser anemometer are, according to datasheets, between -25ºC and 40ºC.

Accuracy

This anemometer is the most precise in the market. The speed accuracy consists on a <0,5% error, while the direction one has a minimum 0.5 degrees error.

Output & Materials

The company producer, Natural Power, does not point out details related to this topics.

Price

The main disadvantage is the price, as this system costs GBP £110,000 (approximately 122000€), although it includes shipping, training and remote power supply.

However, another possibility is to rent it at a cost of £5,000 (~5550€) per month.

TYPE OF ANEMOMETER	ROTATING VANE	HOT WIRE ANEMOMETER	CUP ANEMOMETER	PROPELLER ANEMOMETER	ULTRASONIC ANEMOMETER	LASER ANEMOMETER
Measuring range	0-30 m/s	0-30 m/s	0 to 60-70 m/s	0-100m/s 0-360ºMech; 0-355ºElect	0-70m/s 0-360º no dead band	0-70m/s
Starting threshold	-	0.2m/s	0.5-1 m/s	1m/s	0.01 m/s	2m/s
Operating temperature	-10ºC…60ºC	-	35ºC…60ºC	-50ºC…50ºC	-40ºC…70ºC	-25ºC…40ºC
Accuracy	±1% error or ±0.02m/s below (1m/s)	±3% of reading	±0.2m/s below 15m/s ±2% error above 15m/s	±0.3m/s propeller ±3 degrees for the vane	±0.1 m/s 0..5 m/s ±2% 5..30 m/s ±3% >30 m/s ±2% wind direction	<0.5% error wind speed 0.5º error wind direction
Output	analog, RS232 LCD Display USB port	LCD Display data-logger rarelly RS232	Frequency output Current output Voltage output	AC sine wave voltage signal and DC voltage rarely digital	Analog: (V or I) Digital: RS232, RS422,RS485 NMEA	-
Materials	plastic or rugged metal	plastic and stainless steel probe	stainless steel aluminium, or just plastic	stainless steel anodized with aluminium	stainless steel anodized with aluminium	-
Price	A: $30-$640 B: $200-$815	$300-$600	$250-$1250	2D: $315-$1700 3D:$2500	2D: $1440-$2027 3D: ~ $2400	GBP £110,000 GBP £5,000 per month
Photo						

Table 1: Comparison between all kinds of anemometers. (The pictures are the same as shown in the market study)

Chapter 4. ULTRASONIC ANEMOMETER PURCHASE

This thesis, as it was written before, includes a three-dimensional ultrasonic anemometer purchase. This hi-tech tool helps the research groups to make accurate measurements. It was bought so that wind information was reliable and allowed a correct installation of the wind turbine.

Moreover, it is a perfect way to calibrate the low-cost anemometer. It is a reference in all the tests I have carried out. The low-cost anemometer tries to resemble the sensor as much as possible.

The main advantages of this type of anemometer are that it can detect the vertical component of the wind and has a response time that is virtually instantaneous. Another key advantage is that it has no moving parts so it does not need continuous maintenance.

The main features of an ultrasonic anemometer are shown in the previous market study so they will not be repeated in this section. Hence, the two main different models in the market has been studied.

On the one hand, it is the YOUNG Model 81000 Ultrasonic Anemometer (by R.M. Young Company) and on the other hand it is the new WindMaster manufactured by GILL instruments. Their foremost features are compared in the following table.

Figure 18: RM Young 81000 **[23]** ***and WindMaster*** **[24]** ***respectively***

		RM Young 81000	Wind Master
Wind speed	*Range*	0 to 40 m/s	0 to 45 m/s
	Resolution	0.01 m/s	0.01 m/s
	Accuracy	1%	1.5%
Wind direction	*Range*	0-360º	0-359º
	Resolution	0.01º	0.01º
	Accuracy	2º	2º
Speed of sound	*Range*	300-360 m/s	300-370 m/s
	Resolution	0.01 m/s	0.01 m/s
	Accuracy	0.1%	0.5%
Sonic temperature	*Range*	-50 to 50ºC	-40 to 70ºC
	Resolution	0.01ºC	0.01ºC
Serial output	*Output*	RS-232/485	RS-232/485
	Format	Programmable ASCII	ASCII
	Internal sample rate	4 to 32 Hz	20 or 32 Hz
Power requirement	*Voltage*	12 to 24 Vdc	9 to 30 Vdc
General	*Weight*	1.2 kg	1 kg
	Size	56x17cm	75x24cm
Price		**1.812 €**	**2.273 €**

Table 2: Comparison between both models **[34][35]**

Their features are really similar except for the accuracy, the size and obviously the price. As lots of measurements will be made in different sites in the EhB campus, a light and easy-to-use device is highly recommended.

Furthermore, the most accurate device is required. Consequently, the best option is the RM Young 81000 Model because it meets both requirements: size and accuracy.

Moreover, its price is much lower so there are no doubts about the decision made.

Chapter 5. LOW COST ANEMOMETER PURCHASE

The aim of this section is, once the market research is done, decide which kind of anemometer is going to be used from now on. Going into the market research in depth, a model of each type of anemometer is selected. The criteria used to select these models is it must be representative to its type of anemometer and also a cheap solution.

Finally, they are all compared in a table so that the final decision to buy them is made.

The models chosen are mentioned next:

1.- Rotating vane: *Kestrel 4500* ***[36]***

2.- Cup anemometer: *Cup Anemometer Classic (Wilmers MeBtechnik)* ***[37]***

3.- Propeller anemometer: *WINDLOG Wind Data Logger (Rainwise)* ***[38]***

4.- 3D Propeller anemometer: *27106DT/27106D (R M Young Company)* ***[39]***

Note 1:

Hot wire anemometers, according to the market study, are not considered because of its bad accuracy (±3%). Moreover, its price is similar to Rotating Vane and Cup anemometers, while its accuracy is lower. Hence, it is rejected.

Note 2:

Ultrasonic and Laser anemometers are too expensive to make this low-cost anemometer project. They are very accurate, but the relationship between its features and its price is not worthwhile in this project.

A comparison table with the main features and the price is detailed in the next page.

TYPE OF ANEMOMETER	ROTATING VANE	CUP ANEMOMETER	PROPELLER ANEMOMETER	3D PROPELLER ANEMOMETER
Name	*Kestrel 4500*	*0223 Cup Anemometer Classic*	*WindLog*	*27005T Gill UVW*
Measuring range	0.4-60 m/s	0.4-70 m/s	0.45-67m/s 360º no dead band	0.3-35m/s
Accuracy	±3% error of reading	±0.3m/s below 15m/s ±2% error above 15m/s	±2% error of reading ±22.5 degrees for the vane	?
Output	PC software and USB interface	Frequency output	USB port	Analog output Serial output (32400 model)
Price	Anemometer: $250 Interface: $110	$300-$400	$315	Anemometer: $2400 Propellers: $500
Photo				
Anemometers needed	x3	x3	x3 / x2	x1/x3 (propeller)
Overall amount	$860	$1050	$945/$630	$2400/$1500 (analog)

Table 3: Comparison between the models chosen. (The pictures are the same as shown in the market study)

The “anemometers needed” row means the amount of anemometers needed to build a 3D anemometer, considering that each anemometer can be 1D or 2D.

It is normal that 3 anemometers are required (x3), but two Windlog propeller anemometer (x2) or even one 3D propeller anemometer suggested by RM Young company (x1) can be also used.

Finally, the propeller/windvane anemometer is selected because of the following reasons:

- The windvane, together with the cup anemometer, have the widest wind ranges.

- The output is gathered by an USB port and none of the other diverse sensors compared has it. Thus, there is no need to buy an interface or a converter.

- The foremost reason is the relationship between the price and its features. It is the cheaper sensor but it also includes the USB port and a free Windows software.

- A 3D anemometer can be obtained by mounting only two propeller sensors instead of three. This is a chief characteristic having into account that this tool has to be adjusted and calibrated later on. The less tools needed to build it, the easier the calibration will be.

Chapter 6. CALIBRATION

This step is paramount because it assures the apparatus of measuring accurately. In this section, the calibration of the sensors is explained.

1 Ultrasonic anemometer Calibration

Firstly, the reference anemometer needs to be well calibrated. As it has been explained before, the real reference in this project is an ultrasonic anemometer. The low-cost sensor measurements will be checked with this device.

The RM Young 81000 3D ultrasonic anemometer is calibrated and certified. However, I have tested it in a wind tunnel at the VUB (Vrije Universiteit Brussels) with quite excellent results.

The calibration is carried out in a wind tunnel which has two pitot tubes inside and make up the reference. The wind speed is increased from 3 m/s to 16 m/s and the measurements are done each m/s increased.

Figures 19 & 20: 3D ultrasonic anemometer in the wind tunnel

RESULTS:

Pressure	98043	Pa
Temperature	21,3	ºC
Humidity	43,7	%
Air Density	1,155	Kg/m^3

Table 4: Environmental parameters

First of all, the anemometer is placed with one of its rods in the direction of the flow, so there is a little bit disturbance.

Pitot tube (m/s)	Ultrasonic anemometer (m/s)	Absolute Error (m/s)	Relative Error (%)
3,02	3,01	0,01	0,33
4,12	4,12	0	0
5,13	5,17	0,04	0,77
6,08	6,13	0,05	0,82
7,1	7,18	0,08	1,11
8,08	8,18	0,1	1,22
9,08	9,19	0,11	1,19
10,1	10,23	0,13	1,27
11,06	11,20	0,14	1,25
12,06	12,25	0,19	1,55
13,07	13,25	0,18	1,36
14,03	14,26	0,23	1,61
15,05	15,30	0,25	1,63
16	16,30	0,3	1,84

Table 5: Measurements made with disturbance by ultrasonic anemometer

However, if there is no barrier in the way of the flow the results are on average much better:

Pitot tube (m/s)	Ultrasonic anemometer (m/s)	Absolute Error (m/s)	Relative Error (%)
3,12	3,08	0,04	1,29
4,09	4,05	0,04	0,98
5,11	5,08	0,03	0,59
6,09	6,07	0,02	0,33
7,10	7,07	0,03	0,42
8,08	8,08	0	0
9,07	9,06	0,01	0,11
10,03	10,02	0,01	0,1
11,01	11,01	0	0
12,00	11,97	0,03	0,25
13,03	13,00	0,03	0,23
13,99	13,95	0,04	0,29
15,01	14,93	0,08	0,54
15,99	15,92	0,07	0,44
16,99	16,90	0,09	0,53

Table 6: Measurements made without disturbance by ultrasonic anemometer

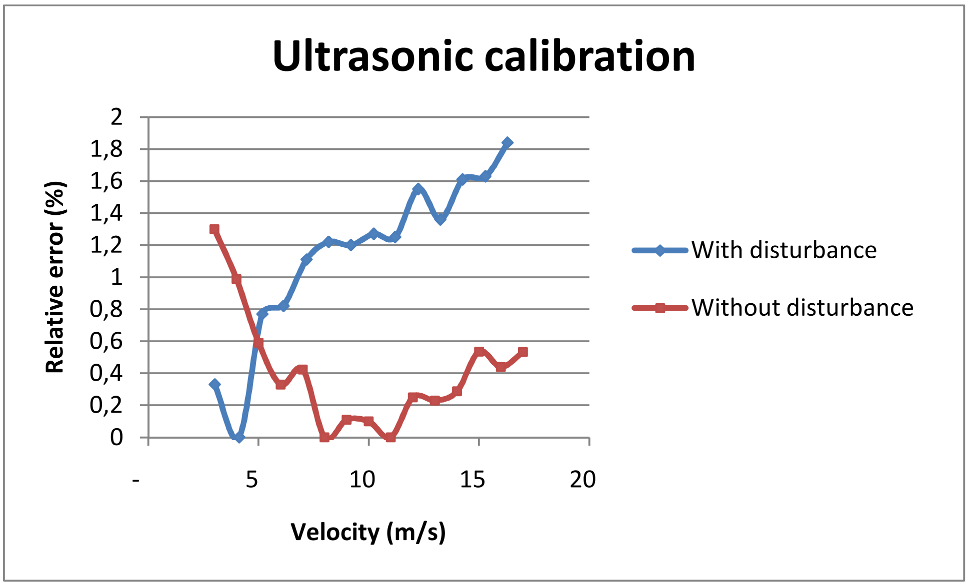


Figure 21: Comparison between measurements with and without disturbance

As it was shown in the datasheets, RM Young Model 81000 is a hi-tech powerful sensor. The accuracy of this system, according to data sheets, is around 1%. The first test made states it is between 1% and 2% in case there is a rod in the direction of the wind flow. Otherwise, the relative error is less than 0,6%.

This means that it can be perfectly used as a reference for the low-cost anemometer.

2 Windlog Calibration

This is a crucial section. The error our measurements have must be known. Hence, the two propeller anemometers are tested in the wind tunnel (at VUB).

The Windlog anemometer is set up between the pitot tubes (picture below) and tested in a wind range from 3 m/s to 16 m/s. The measurements are done every m/s and both Windlogs are similar, so the process is repeated.


Figure 22 & 23: Windlog1 and Windlog2 in the wind tunnel

RESULTS:

Windlog 1:

Pressure	98081,5	Pa
Temperature	21,45	ºC
Humidity	42,9	%
Air Density	1,155	Kg/m^3

Table 7: Environmental parameters

The results are shown in the following tables:

Pitot tube (m/s)	Windlog (m/s)	Absolute Error (m/s)	Relative Error (%)
3,16	3,1	0,06	1,90
4,09	3,8	0,29	7,09
5,14	4,8	0,34	6,61
6,1	5,6	0,5	8,20
7,13	6,6	0,53	7,43
8,1	7,4	0,7	8,64
9,08	8,3	0,78	8,59
10,12	9,1	1,02	10,08
11,07	10	1,07	9,67
12,04	10,8	1,24	10,30
13,05	11,7	1,35	10,34
14,04	12,6	1,44	10,26
15,06	13,4	1,66	11,02
16,06	14,3	1,76	10,96

Table 8: Windlog 1 measurements

Windlog 2:

Pitot tube (m/s)	Windlog (m/s)	Absolute Error (m/s)	Relative Error (%)
3,16	3,1	0,06	1,90
4,09	3,8	0,29	7,09
5,12	4,8	0,32	6,25
6,11	5,7	0,41	6,71
7,11	6,6	0,51	7,17
8,09	7,4	0,69	8,53
9,06	8,2	0,86	9,49
10,07	9,1	0,97	9,63
11,04	9,9	1,14	10,33
12,02	10,8	1,22	10,15
13,1	11,7	1,4	10,69
14,07	12,6	1,47	10,45
15,06	13,4	1,66	11,02
16,06	14,3	1,76	10,96

Table 9: Windlog 2 measurements

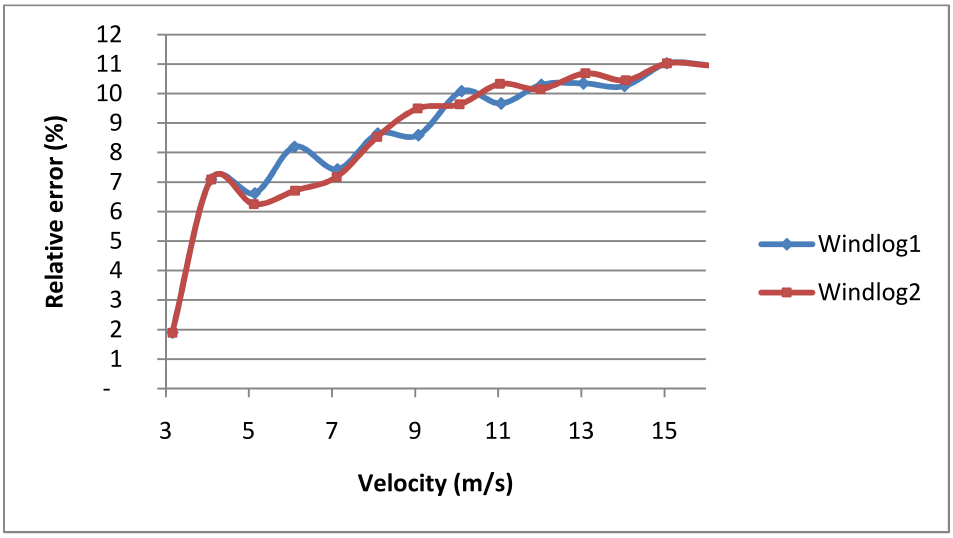


Figure 24: 1st Comparison between Windlog1 and Windlog2 calibration

As it can be seen in the information gathered there are some big errors that have to be considered when we measure. The data sheets provided showed a maximum error of 2%, however, this disproves that, because we reach up to 10-11% errors. I kept in touch with the manufacturers to try to solve this and I got an agreement to work with them testing and improving their products.

After having tested the anemometers again with a special firmware version developed just for this case, the manufacturers concluded that they had to upload the program inside the anemometers to improve the quality of the measurements. They sent me the new program and the Windlogs were tested as it is described next.

The new calibration process consists of the Windlog anemometer set up between the pitot tubes and tested in a wind range from 3 m/s to 25 m/s. The measurements are done every m/s until 10 m/s and then every 2 m/s and both Windlogs are similar so the process is repeated.

RESULTS:

Windlog 1:

Pressure	98081,5	Pa
Temperature	21,64	ºC
Humidity	42,0,7	%
Air Density	1,154	Kg/m^3

Table 10: Environmental parameters

Pitot tube (m/s)	Windlog (m/s)	Absolute Error (m/s)	Relative Error %
3,11	3	0,11	3,54
4,04	3,8	0,24	5,94
5,07	4,9	0,17	3,35
6,05	5,9	0,15	2,48
7,04	6,8	0,24	3,41
8,09	7,8	0,29	3,58
9,07	8,7	0,37	4,08
10,04	9,7	0,34	3,39
12,01	11,6	0,41	3,41
14	13,5	0,5	3,57
16,01	15,3	0,71	4,43
18,02	17,4	0,62	3,44
20,04	19,3	0,74	3,69
22,03	21,1	0,93	4,22
25,04	24	1,04	4,15

Table 11: Windlog 1 measurements

Windlog 2:

Pitot tube (m/s)	Windlog (m/s)	Absolute Error (m/s)	Relative Error %
3,11	3	0,11	3,54
4,04	4,1	-0,06	5,94
5,07	4,9	0,17	3,35
6,05	5,9	0,15	2,48
7,04	6,8	0,24	3,41
8,09	7,8	0,29	3,58
9,07	8,9	0,17	1,87
10,04	9,7	0,34	3,39
12,01	11,6	0,41	3,41
14	13,5	0,5	3,57
16,01	15,5	0,51	3,19
18,02	17,4	0,62	3,44
20,04	19,3	0,74	3,69
22,03	21,1	0,93	4,22
25,04	24,2	0,84	3,35

Table 12: Windlog 2 measurements

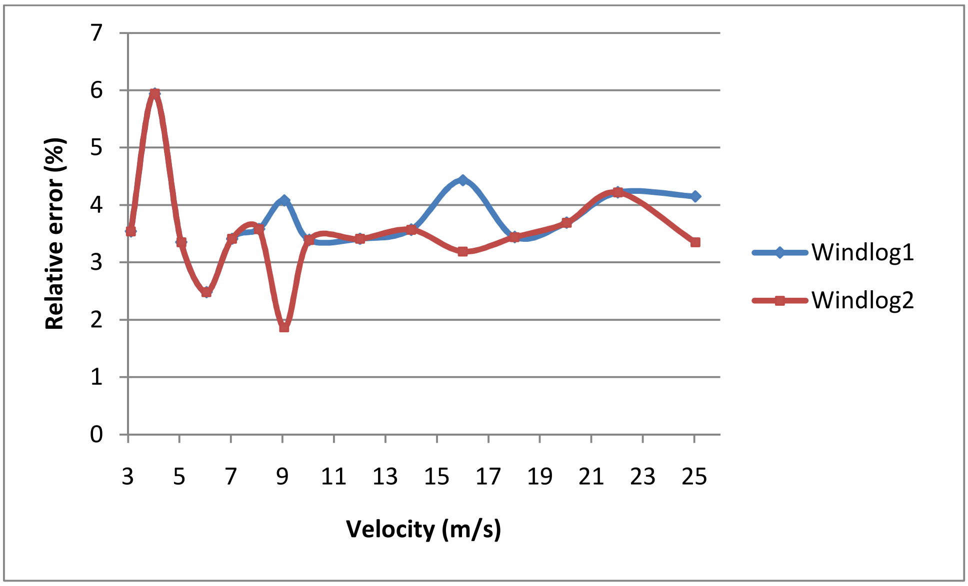


Figure 25: 2nd Comparison between Windlog1 and Windlog2 calibration

As it is shown above, there are still errors bigger than 2% errors mentioned in data sheets. Actually, the manufacturers admitted that their device was not that accurate. They repeated the tests in their wind tunnel and informed that my results were correct.

Hence, according to the figure 25, future measurements will have an average error of 3-4%. The reason for larger errors at low speed is because the Windlogs get one count for every one revolution of the anemometer. At low speed there are low counts that correlates to a lower resolution of wind speed.

CONCLUSIONS:

- Thanks to this calibration process we could really improve our device accuracy. The error reduction was huge, from up to 10%, when the sensors were purchased, to 4%.

- This calibration process gave me the possibility to get an agreement to work with the Rainwise company and this collaboration resulted in an improved product for the company and a more accurate sensor for this thesis.

- To sum up, as the low cost anemometer will always measure a lower wind speed, the corresponding error (3-4%) has to be added to in order to obtain the real wind speed.

Chapter 7. ASSEMBLY

In this section it will be explained how two WindLog propeller anemometers are mounted to become a 3D anemometer.

Firstly, it is needed to explain that two Windlog anemometers are chosen instead of three because of one of the goals of this project, the price. A low-cost anemometer is desired, so for the same device, the smaller budget, the better project. However, the assembly and the calibration are more difficult.

Hence, the 3D built anemometer consists basically of two Windlogs, a mast and a elbow flush joiner to make the Windlogs run perpendicular to each other.

Figure 26, 27 & 28: Two Windlogs, the mast and the elbow flush joiner.

Firstly, the two Windlogs must be mounted perpendicularly in order their shafts to represent X and Z axis respectively. To make this possible, the top of each Windlog has to be dismounted so that the elbow flush joiner can be placed in the shafts.

Figure 29: Windlogs mounted perpendicularly

Another paramount step is that the North signal in the vertical shaft must point to the Y axis and the North signal in the horizontal shaft must point upwards, Z axis.

Secondly, the black mast has to be extended to the desired height, positioning the leg braces parallel to the ground . Then, the vertical Windlog has to fit in the top of the mast properly and tightly.

Figure 30 & 31: Windlogs properly fit in the top of the mast

Finally, the dataloggers boxes have to be attached to the mast. This last step can be done at any height because their position does not disturb the measurements.

Figure 32 & 33: Low-cost anemometer in an EhB roof

Note: The vane of the Windlog whose shaft is placed horizontally and measures the vertical speed, needs a balance weight so that when the vane is placed horizontally it does not move. To that end, some black tape has been placed around the vane:

Figure 34: Detail of black tape placed around the vane

Chapter 8. MEASUREMENTS

This section involves the explanation of how a 3D wind vector is measured by the low-cost anemometer, the mathematical expressions of its components, and how to proceed to do a measurement.

1 3D vector construction

In a wind measurement, three spatial components are needed: the wind speed in the axis X, Y and Z, respectively. To reach this 3D vector there are diverse possibilities and combinations. One possibility is measuring the three different components of the wind separately.

However, this requires three wind sensors or anemometers, but there are only two available. It is also possible to obtain the three components with two anemometers, by measuring the wind in two different perpendicular planes. This is explained with more details next.

One anemometer is mounted to gather information in the horizontal plane (XY).

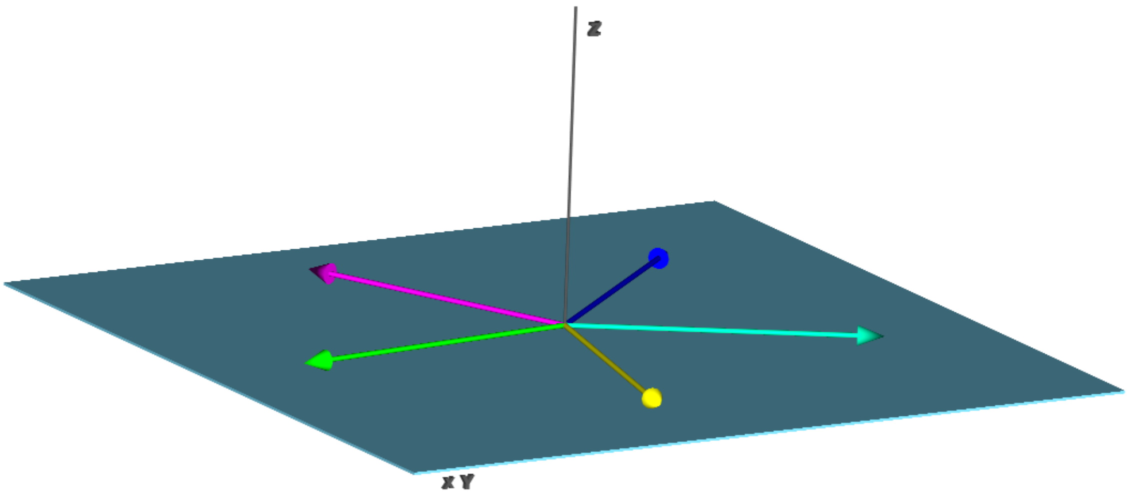


Figure 35: Measurements in the horizontal plane made by the first anemometer

The second anemometer is mounted perpendicularly and it measures the wind in the YZ plane (it can also be the XZ plane). It is important to point out that these planes give us the Z component, this is, the vertical component, which is the only one left.

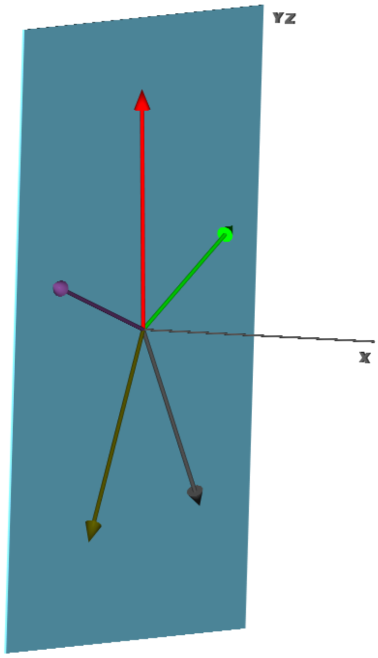


Figure 36 : Measurements in the vertical plane made by the second anemometer

Each anemometer obtains a wind speed in a fixed plane and an angle with respect to a reference axis in that plane. Both vectors can be combined to build a 3D vector.

For example, XY and YZ planes are chosen, then the gathered information shows two different vectors which share the Y component. This is also a way to know that the wind sensor is properly calibrated. Hereby, as shown in the picture below, all the components needed are known.

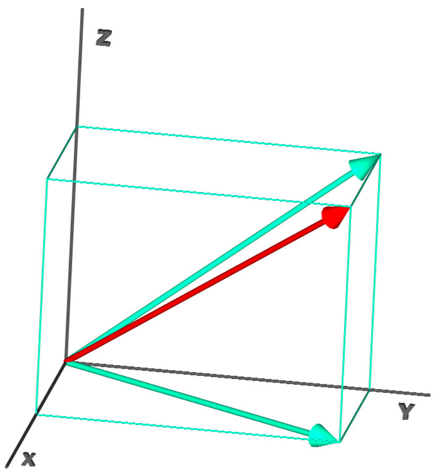


Figure 37: 3D wind vector construction from two components (XY and YZ)

2 Wind components

In this section a 3D wind vector is constructed from the measurements using two perpendicular anemometers. Moreover, their mathematical expressions are obtained.

YZ Plane

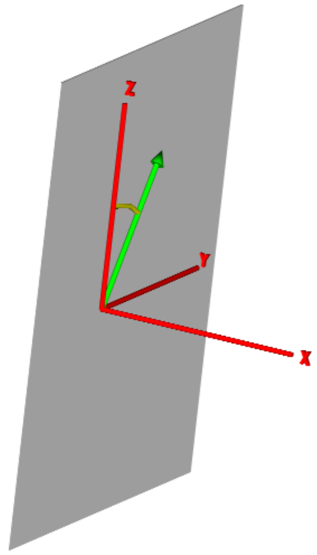


Figure 38: Windlog measurements in ZY plane

$\boldsymbol{F_{yz}}$ is the wind speed measured by the first anemometer in the YZ plane

$\boldsymbol{\alpha}$ is the clockwise angle between the Z axis (0º) and the vector F_{yz}

XY Plane

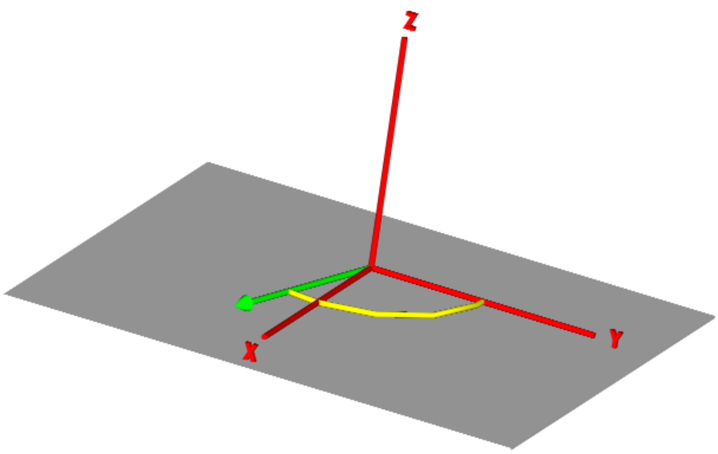


Figure 39: Windlog measurements in XY plane

$\boldsymbol{F_{xy}}$ is the wind speed measured by the second anemometer in the XY plane

$\boldsymbol{\beta}$ is the clockwise angle between the Y axis (0º) and the vector F_{xy}

These two wind speeds, F_{xy} and F_{yz}, together with the angles α and β, form the information gathered from both anemometers. Here there are the different components that are required:

SENSOR 1:

$$\boldsymbol{F_y = F_{yz} \cdot \sin\alpha}$$

$$\boldsymbol{F_z = F_{yz} \cdot \cos\alpha}$$

SENSOR 2:

$$\boldsymbol{F_x = F_{xy} \cdot \sin\beta}$$

$$\boldsymbol{F_y = F_{xy} \cdot \cos\beta}$$

These components, F_x, F_y and F_z can be represented in the wind rose. As it was mentioned before, Y component will always be aligned on the North.

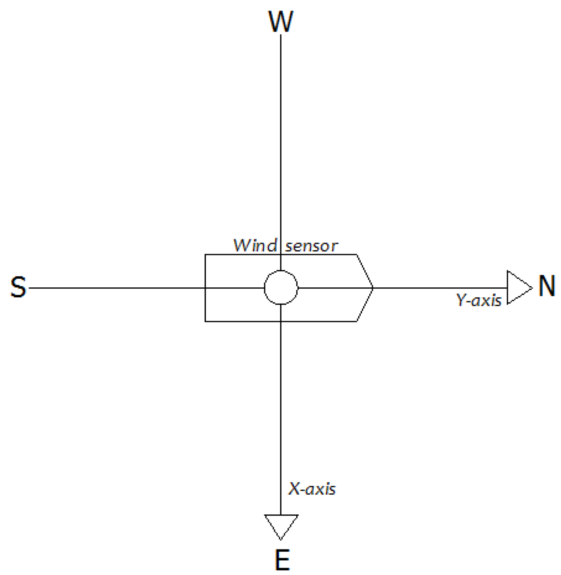


Figure 40 : Position of the Windlog related to cardinal points

To sum up, Y component is aligned to North and X component is aligned to East, while Z component is the vertical component.

3 Wind measurement

This section explains how to make a correct installation of the equipment and obtain a right measurement. The following conditions are required:

- Make sure that the batteries are correctly mounted. This first step can be omitted if the anemometers are directly connected to the laptop through the USB cable.

- Place the mast and the anemometer over a flat surface and secure them. To this end, position the leg braces parallel to the ground.

- Align the Y axis (0º) to North. This is easy because a North signal is written in the vertical shaft of each anemometer.

- If the previous steps have been followed, everything is ready, so it is only needed to wait the desired time and then connect the USB cable to collect the data. This last step is explained in the section number 10 of this thesis.

- To know the real wind speed these data need to be corrected with the respective correction factor of the calibration table.

Chapter 9. COMPARISON

Once the Windlog anemometers are calibrated they are tested outside and checked whether their measurements are correct. To this end, the ultrasonic anemometer is used as a reference.

The 3D low-cost anemometer and the ultrasonic sensor have been eventually installed together in a roof at the ErasmusHogeschool for three days and the corresponding data has been gathered to compare both models.

Figure 41: Low-cost and ultrasonic anemometer placed in a roof of EhB

These tests have been carried out at the end of May and consequently I got only low winds (<3m/s). Ten measurements were made during three days comparing each wind speed component measured by the low-cost anemometer and the ultrasonic device.

The calibration process provided the error in wind velocities above 3 m/s. However, this comparison allows to know the anemometer behavior in lower speeds. Each component is calculated with formulas from page 66.

$$F_x = F_{xy} \cdot \sin\beta$$

$$F_y = F \cdot cos\ \beta$$

$$F_z = F \cdot cos\ \alpha$$

Data is divided in the diverse wind speed components measured by the ultrasonic device (U, V, W) and the ones measured by the low-cost anemometer (F_x, F_y, F_z). The results are shown in the following tables:

U (m/s)	F (m/s)	β (º)	Fx	Absolute error
-1,99	2	270	-2,00	0,01
-1,24	1,8	247	-1,66	0,42
-1,78	1,8	270	-1,80	0,02
-1,35	1,3	247	-1,20	-0,15
-0,83	0,9	202	-0,34	-0,49
-1,38	1,6	225	-1,13	-0,25
-1,96	2	292	-1,85	-0,11
-2,53	2,6	292	-2,41	-0,12
-1,27	1,6	270	-1,60	0,33
-0,43	0,5	202	-0,19	-0,24
-2,1	1,8	296	-1,62	-0,48
1,64	1,8	135	1,27	0,37
2,16	2,4	135	1,70	0,46
1,95	2	135	1,41	0,54
0,12	0,5	180	0,00	0,12
-0,98	0,9	270	-0,90	-0,08
-0,65	0,7	270	-0,70	0,05
-1,18	2	315	-1,41	0,23
-0,86	0,7	270	-0,70	-0,16
-1,34	1,5	270	-1,50	0,16
0,52	0,5	135	0,35	0,17
-0,95	1,2	270	-1,20	0,25
-2,25	2,1	270	-2,10	-0,15
-1,32	1,7	247	-1,56	0,24
0,45	0,9	135	0,64	-0,19
-1,2	1,2	225	-0,85	-0,35
-1,88	2,2	247	-2,03	0,15
-1,89	2,2	247	-2,03	0,14
-2,23	2,6	296	-2,34	0,11
-1,14	1,8	296	-1,62	0,48

Table 13: U component (measured by ultrasonic) vs F_x (measured by low-cost device)

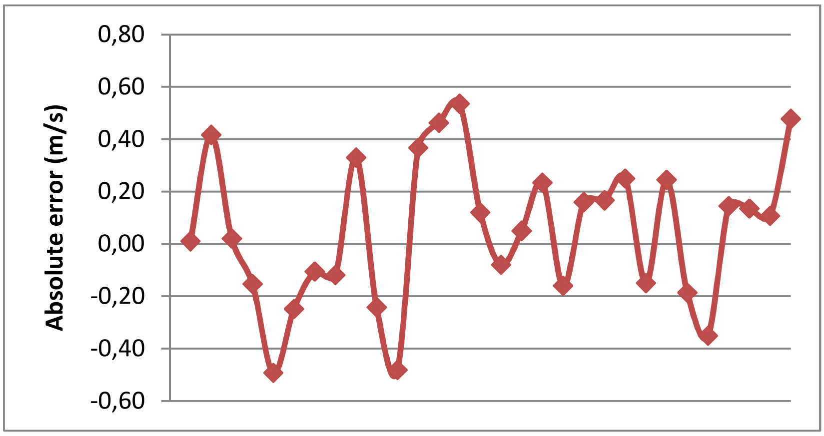


Figure 42: U component. Absolute error (m/s) in 30 measurements

V (m/s)	F (m/s)	β (º)	Fy	Absolute error
-1,028	0,8	135	-0,57	-0,46
-0,4	0,5	202	-0,46	0,06
-2,39	2,9	135	-2,05	-0,34
-1,14	1,1	157	-1,01	-0,13
-0,65	0,7	135	-0,49	-0,16
-1,31	1,6	157	-1,47	0,16
-1,51	1,3	180	-1,30	-0,21
0,45	0,5	67	0,20	0,25
1,23	1,2	22	1,11	0,12
-2,05	2,4	135	-1,70	-0,35
-1,41	1,8	135	-1,27	-0,14
-1,2	1,6	135	-1,13	-0,07
-1,06	2,2	135	-1,56	0,50
-1,49	1,8	135	-1,27	-0,22
2,55	2,7	360	2,70	-0,15
1,38	2,2	67	0,86	0,52
-0,94	1,3	157	-1,20	0,26
-1,63	2	135	-1,41	-0,22
0,57	0,5	337	0,46	0,11
2,27	2,5	337	2,30	-0,03
-2,03	2,2	225	-1,56	-0,47
-1,16	1,2	157	-1,10	-0,06
-1,06	0,8	157	-0,74	-0,32
-2,43	2,2	180	-2,20	-0,23
-1,73	1,9	180	-1,90	0,17
-0,84	0,9	157	-0,83	-0,01
-1,29	1,3	180	-1,30	0,01
-1,34	2	135	-1,41	0,07
2,31	2,5	45	1,77	0,54
1,17	0,9	45	0,64	0,53

Table 14: V component (measured by ultrasonic) vs F_y (measured by low-cost device)

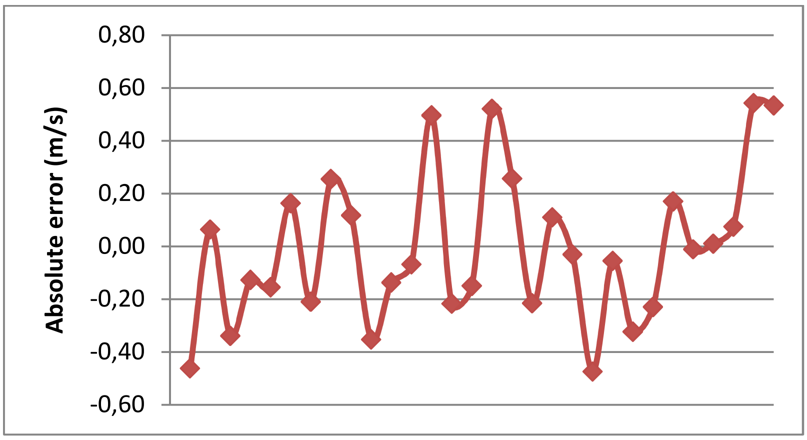


Figure 43: V component. Absolute error (m/s) in 30 measurements

W (m/s)	F (m/s)	a (º)	Fy	Absolute error
-1,355	1,2	247	-0,47	0,89
-1,235	1,2	247	-0,47	0,77
-0,325	0,5	315	0,35	0,68
1,825	1,9	315	1,34	-0,48
2,625	2,4	337	2,21	-0,42
0,535	1,2	67	0,47	-0,07
2,505	2,3	315	1,63	-0,88
1,465	1,9	22	1,76	0,30
0,385	0,4	45	0,28	-0,10
1,475	1,8	45	1,27	-0,20
2,555	2,7	315	1,91	-0,65
1,805	2	67	0,78	-1,02
0,385	0,4	22	0,37	-0,01
-0,09	0,4	0	0,40	0,49
-2,0812	2,4	157	-2,21	-0,13
-2,2812	2,6	202	-2,41	-0,13
-0,2212	0,9	45	0,64	0,86
1,0712	0,8	67	0,31	-0,76
-2,0312	2,3	202	-2,13	-0,10
1,2812	0,7	337	0,64	-0,64
0,6412	0,8	67	0,31	-0,33
2,0812	2,7	67	1,05	-1,03
0,3712	0,4	22	0,37	0,00
0,5912	0,5	247	-0,20	-0,79
1,3512	0,8	360	0,80	-0,55
-0,5812	0,7	315	0,49	1,08
-2,1012	1,8	202	-1,67	0,43
0,4812	0,5	22	0,46	-0,02
2,0412	1,8	360	1,80	-0,24
-2,3112	2,7	157	-2,49	-0,17

Table 15 : W component (measured by ultrasonic) vs F_z (measured by low-cost device)

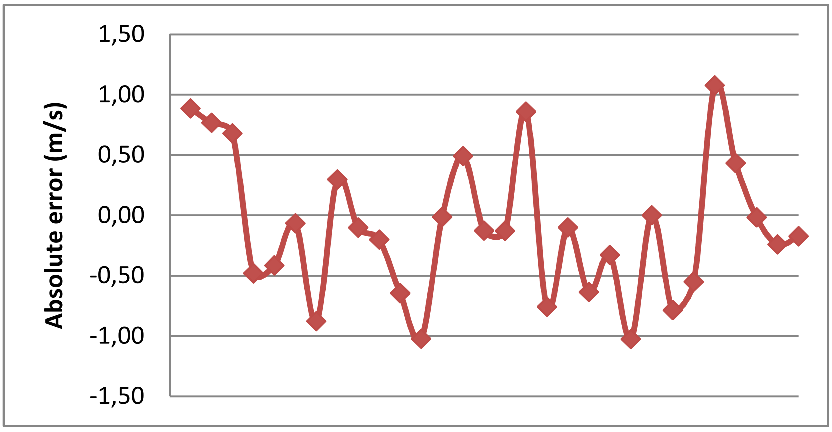


Figure 44: W component. Absolute error (m/s) in 30 measurements

CONCLUSIONS

As the wind speed range measured was quite reduced, deductions cannot be extended to the whole wind range. However, some conclusions can be pointed out considering low wind speeds:

- Measurements corresponding to XY plane (horizontal plane) are more accurate than the vertical component of the wind.

- U and V components have in this case (low wind velocities) a maximum error of ±0,60 m/s. The gathered data is normally around the null deviation.

- W component data is more variable, the data is far from the null deviation and the maximum error measured is bigger: ±1 m/s.

- This test was also useful to see how the anemometer worked in velocities lower than the ones tested in the wind tunnel.

- In the wind range studied, these errors are equivalent to large relative errors. However, this is due to the fact that at low speeds the resolution is also low.

- These errors must be taken into account when future measurements are done.

Chapter 10. DATA RETRIEVING

1 Low-cost anemometer

Windsoft is a software provided with the Windlog propeller anemometers. This program let us see all the gathered information in the screen of a PC. It is intuitive and easy-to-use and a file can be created to store wind data. Next, is explained how to use this program.

At the beginning the following screen is displayed:

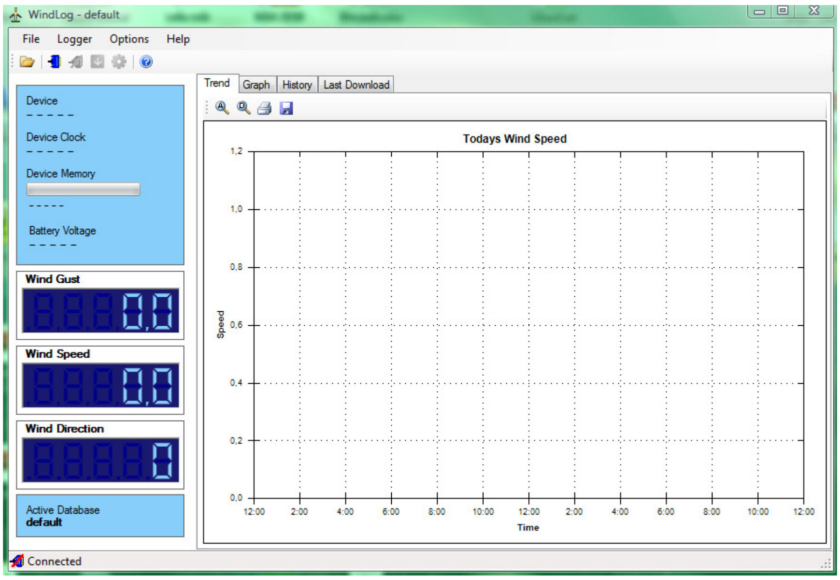


Figure 45: Main screen when Windsoft is run

First of all, a database has to be selected. What is more, if it is the first time this program is used a new database must be created choosing the time interval and the units.

It is paramount that the Windlog's interval matches the database, otherwise the averages will not be correct. An interval of 1 minute and m/s as the unit will be used from now on in the database.

Settings

Secondly, the Windlog must be connected to the USB port and *Logger/Connect...* button pressed.

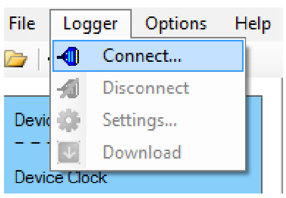


Figure 46: Logger/Connect... Screenshot

Then a new ComForm window is opened and the selection of the USB COM port is needed. If somebody does not know which port is suitable, can press *Device Manager* and check it properly.

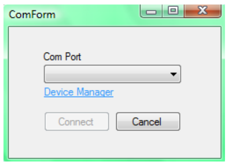


Figure 47: Configuring Port Screenshot

Once the Windlog is correctly connected, the set up is needed. Pressing *Logger/Settings…* the user will have access to the following Logger Settings entry box.

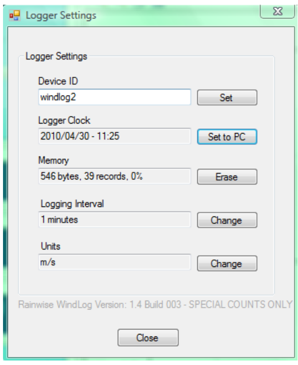


Figure 48: Windlog settings Screenshot

Moreover, the name assigned to the Windlog can be easily changed. I will call the anemometers Windlog1 and Windlog2. Furthermore, PC clock must be synchronized, memory cleared, the interval changed, and finally the units. This must be done always the device is connected or the software restarted.

Display data

Hence, everything is prepared to start measuring. However, next is explained how to see the data on the PC. There are 4 different panes which are accessible from the following buttons.

Trend pane:

It consists on a real time graphical presentation of wind measurements. On the one hand, the red trace indicates wind gust velocity (the maximum) and on the other hand, the blue trace denotes average wind velocity.

On the left toolbox, gust velocity, average velocity and wind direction are also displayed.

Graph pane:

This pane shows us a graph of the selected data. The beginning and the ending period must be specified and the graph will be displayed.

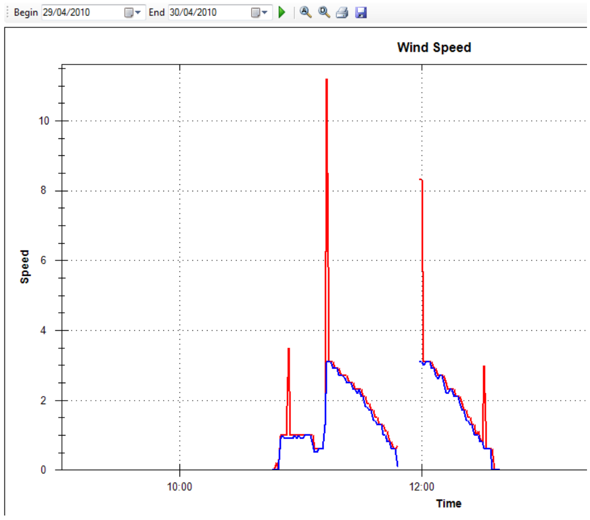


Figure 49: Graph pane Screenshot

History Pane:

In this section a table is presented. You can check the history data of one specific day which needs to be selected. All the data collected that day will appear in this table divided in four columns: time, average speed, gust velocity and wind direction.

jueves , 29 de abril de 2010 | Refresh | < | >

Time	Average Speed	Gust	Direction
29/04/2010 11:14	3,1	3,1	90
29/04/2010 11:15	3,1	3,1	90
29/04/2010 11:16	2,9	3,1	90
29/04/2010 11:17	2,9	2,9	90
29/04/2010 11:18	2,9	2,9	90
29/04/2010 11:19	2,7	2,9	90
29/04/2010 11:20	2,7	2,7	90
29/04/2010 11:21	2,7	2,7	90
29/04/2010 11:22	2,6	2,7	90
29/04/2010 11:23	2,5	2,7	90
29/04/2010 11:24	2,5	2,5	90
29/04/2010 11:25	2,5	2,5	90
29/04/2010 11:26	2,3	2,5	90
29/04/2010 11:27	2,3	2,3	90
29/04/2010 11:28	2,2	2,3	90
29/04/2010 11:29	2,3	2,3	90
29/04/2010 11:30	2,1	2,3	90
29/04/2010 11:31	2,1	2,1	90
29/04/2010 11:32	1,8	2,1	90
29/04/2010 11:33	1,8	1,9	90
29/04/2010 11:34	1,7	1,9	90
29/04/2010 11:35	1,7	1,7	90

Figure 50: History pane Screenshot

Export data

Data can be exported and stored in a file apart. In order to do this, *File/Export Data…* will be pressed. Then the beginning and the ending dates among which we want to storage the data must be finally set.

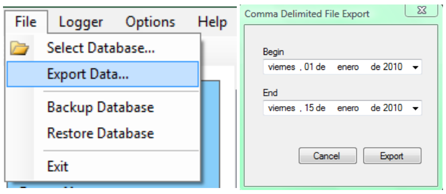


Figure 51: Exporting data Screenshots

Finally the name of the file is required and the extension is .csv. This extension belongs to a 'comma delimited file', this is a database where each record is a single line and each field in the record is indicated by a comma. A common program that opens these files is Microsoft Office.

2 Ultrasonic anemometer

The last part of this thesis involves a program that lets the user log the data of the ultrasonic anemometer. This is made using the C programming language and a program called *Dev-C++.*

The program just asks the user about the date, and the baudrate and serial output format desired. Then, it opens the Serial port (RS-232 connection) and starts reading the data. Finally, this gathered information is stored in an extern file called '*ultrasonic_data.txt*'

The source code is shown next:

```
/* MAY 2010
  ERASMUSHOGESCHOOL BRUSSELS
  PROJECT: 3D LOW COST ANEMOMETER
  STUDENT: ALEJANDRO SOLA ALZUETA (UPNA)

************* RM YOUNG 81000 ULTRASONIC ANEMOMETER *************"
This program collects data from a 3D ultrasonic anemometer and
save it to a file called 'ultrasonic_data.txt' */

#include <windows.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <conio.h>

//functions used
void heading(void);
void outputBaud(void);
void outputFormat(void);
static HANDLE openPort(int rate);
void dateSetup(struct date *time);
```

```
struct date
{       int day,month;
            };

main() //Body of the program
{
            int B,F,BAUDRATE,msrmt,SUCCESS=1,cont=1,i;
            FILE *file_ptr;
            BOOL status;
            DWORD count;
            HANDLE h;
            struct date time;
            char buffer[21];//buffer where the data is received from Serial Port
                        //21 is the size of the biggest string received

            dateSetup(&time);// The date is established
            system("cls");//Screen cleared
            outputBaud(); //Baudrate configuration
            B=getche();

            switch(B)
    {  case '1': BAUDRATE=4800; break;
       case '2': BAUDRATE=9600; break;
       case '3': BAUDRATE=38400; break;
    }

            heading();
            outputFormat(); //Serial output format menu is called
            F=getche();
```

```
system("cls");
heading();//The heading of the program is written
printf("\n\n\n\n NUMBER OF MEASUREMENTS DESIRED: ");
scanf("%d",&msrmt);



if(SUCCESS=1) {
file_ptr=fopen("ultrasonic_data.txt","a");//The file is opened and written
fprintf(file_ptr,"\n\n   DATE (dd/mm): %d/%d\n\n",time.day,time.month);
//The date is copied in the file

h = openPort(BAUDRATE);//The function is called and the port opened

if (h == INVALID_HANDLE_VALUE) {//The port cannot be opened
        fprintf(stderr, "Port COM1 cannot be opened!");
        getch();
        exit(EXIT_FAILURE);
            }
while(cont<=msrmt) {//If number of measurements are less than desired

status = ReadFile(h,buffer,22,&count,NULL);//The port is read

if (status == FALSE) {//The port cannot be read
            fprintf(stderr, "Error reading!\n");
        system("PAUSE");
            exit(EXIT_FAILURE);
    }
else{

  switch(F) //Type of serial output data
   {case '1': printf("\n     U     V     Z\n");
```

```
            fprintf(file_ptr,"\n    U     V    Z\n");    break;
        case '2': printf("\n 2D SPEED\n");
            fprintf(file_ptr,"\n 2D SPEED\n"); break;
        case '3': printf("\n 3D SPEED\n");
            fprintf(file_ptr,"\n 3D SPEED\n"); break;
    }

      for(i=0;i<21;i++){
            printf("%c",buffer[i]);//Measurement is printed
            fprintf(file_ptr,"%c",buffer[i]);//Data copied in the file
              }
            fprintf(file_ptr,"\n");
    }
      cont++; //Measurements made are counted

                }

      fclose(file_ptr); //The file is closed
      printf("\n\n\n\n\n\n DATA STORED IN: 'ultrasonic_data.txt'");
      printf("\n\n\n <PRESS ANY KEY TO EXIT...>");
      getch();
       }
      CloseHandle(h); //The serial port is closed

}

/*****************************************************
This funtion opens the Serial Port. COM1 port is chosen as default
*****************************************************/

static HANDLE openPort(int rate)
```

```
{
        HANDLE      h;
        DCB         dcb;
        COMMTIMEOUTS tmo;
        int         status;

        h = CreateFile("\\\\.\\COM1",
           GENERIC_READ | GENERIC_WRITE,
           0,
           NULL,
           OPEN_EXISTING,
           0,
           NULL);
        if (h == INVALID_HANDLE_VALUE) {
    return h;
                  }
        status = GetCommState(h,&dcb); //New values for the communication are get
        if (status == 0) {
          CloseHandle(h);
          return INVALID_HANDLE_VALUE;
           }

        dcb.BaudRate = rate;
        dcb.ByteSize = 8;
        dcb.Parity   = NOPARITY;
        dcb.StopBits = ONESTOPBIT;

        status = SetCommState(h, &dcb);//Communication with new values
        if (status == 0) {
          CloseHandle(h);
          return INVALID_HANDLE_VALUE;
```

```
        }

    status = GetCommTimeouts(h,&tmo);//Time-out values are obtained
    if (status == 0) {
      CloseHandle(h);
      return INVALID_HANDLE_VALUE;
        }

    tmo.ReadIntervalTimeout        = 0;
    tmo.ReadTotalTimeoutConstant   = 0;
    tmo.ReadTotalTimeoutMultiplier = 0;

    status = SetCommTimeouts(h,&tmo);//Communication time-out is set
    if (status == 0) {
      CloseHandle(h);
      return INVALID_HANDLE_VALUE;
        }

    return h;  //h=TRUE  -> port succesfully opened
               //h=FALSE -> port not opened
}

/***************************************************
This function prints a heading in the screen
****************************************************/
void heading(void)
{
printf("\n**************************************************************");
printf("\n************* RM YOUNG 81000 ULTRASONIC ANEMOMETER *************");
printf("\n This program collects data from a 3D ultrasonic anemometer and \n");
printf(" save it to a file called 'ultrasonic_data.txt'.");
```

```
printf("\n Port COM1 is defined as default.");
printf("\n Anemometer should be firstly configurated with HyperTerminal. ");
printf("\n*****************************************************************");
        }

/****************************************************
This function sets up the date
****************************************************/
void dateSetup(struct date *time)
{
    struct date sample;
    heading();
    printf("\n\n\n\n ENTER THE DAY (dd):");
    scanf("%d",&sample.day);
    printf("\n ENTER THE MONTH(mm):");
    scanf("%d",&sample.month);
    *time=sample;
        }

/****************************************************
This function sets up the Baudrate
****************************************************/
void outputBaud(void)
{   heading();
    printf("\n\n\n\n  CONFIGURATION PORT");
    printf("\n\n     BAUDRATE ");
    printf("\n\n\n     1.- 4800");
    printf("\n     2.- 9600");
    printf("\n     3.- 38400");
    printf("\n\n\nSelect an option: ");
    }
```

```
/*****************************************************
This function sets up the data output format
*****************************************************/
void outputFormat(void)
{
    system("cls");
    heading();
    printf("\n\n\n\n  CONFIGURATION PORT");
    printf("\n\n\n  SERIAL OUTPUT FORMAT ");
    printf("\n\n\n     1.- UVW");
    printf("\n     2.- 2D SPEED");
    printf("\n     3.- 3D SPEED");
    printf("\n\n\nSelect an option: ");
    }
```

Some screenshots are displayed next:

This first screenshot shows when the date is entered. This date will appear in the corresponding file which will store the data.

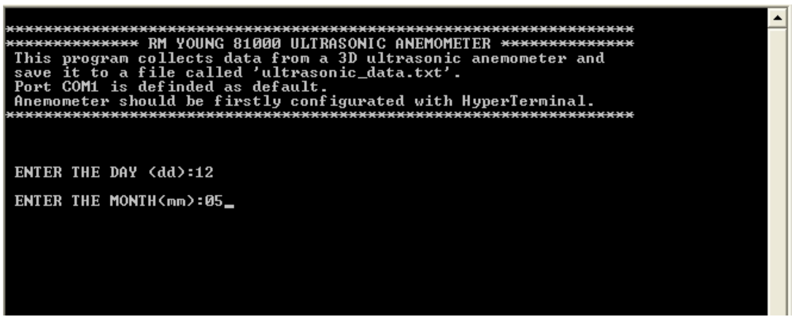


Figure 52: Entering the date screenshot

This next screenshot asks the user which Baudrate is going to be used. This Baudrate has to be the same as the one selected in the ultrasonic configuration.

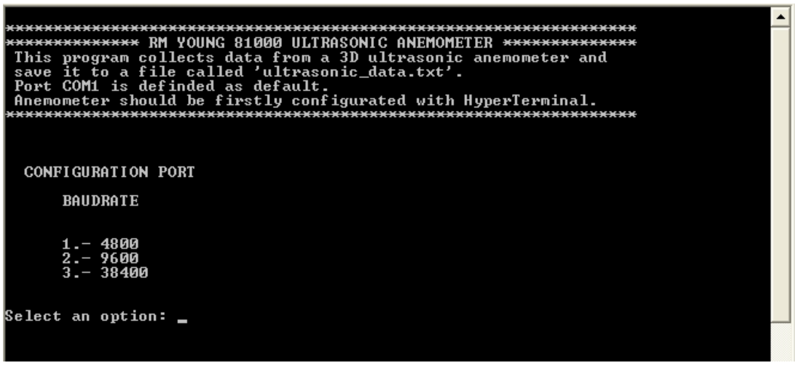


Figure 53: Entering the baudrate screenshot

The following screenshot offers diverse possibilities of seeing the data: UVW (three components), 2D speed (wind speed in the horizontal plane) and 3D speed (3D wind speed).

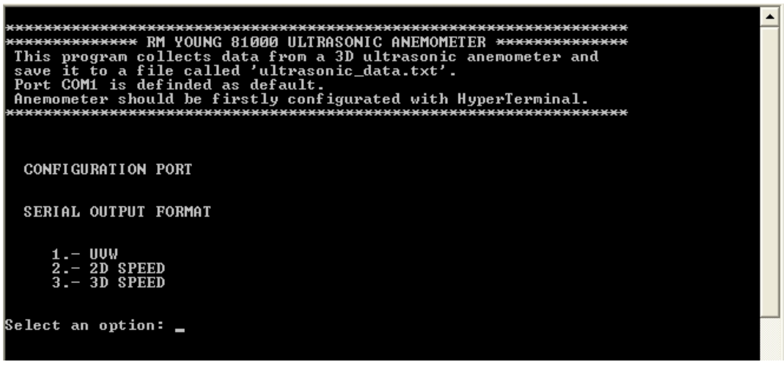
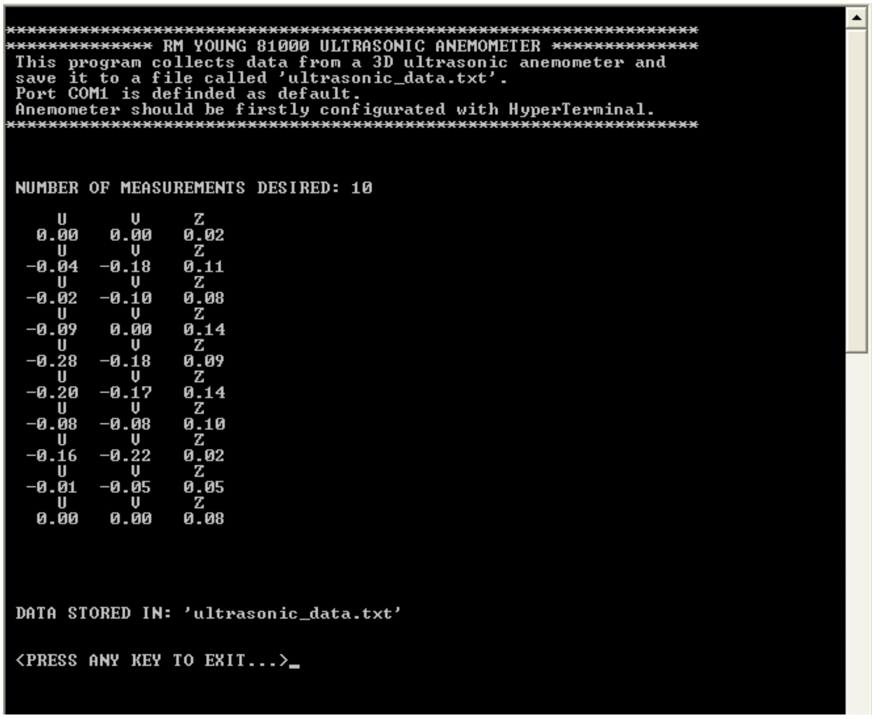


Figure 54: Entering the serial output format screenshot

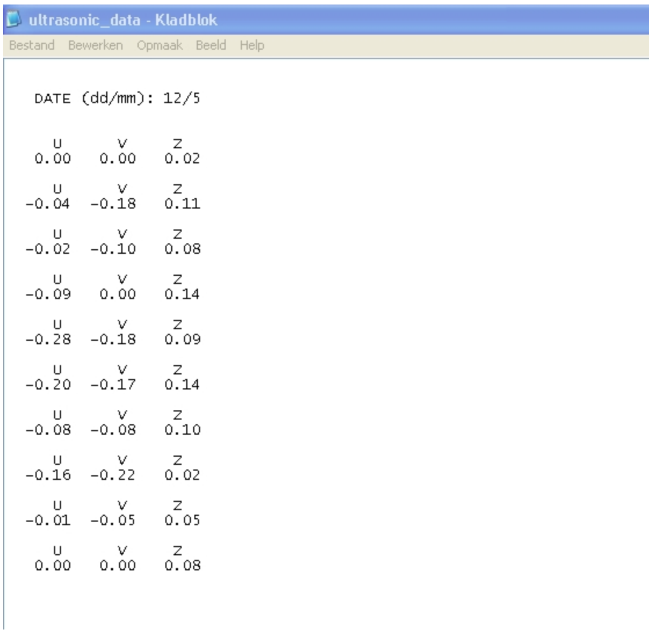
Finally, the data which is being collected can be seen in the next screenshot:



```
******************************************************************
************* RM YOUNG 81000 ULTRASONIC ANEMOMETER **************
 This program collects data from a 3D ultrasonic anemometer and
 save it to a file called 'ultrasonic_data.txt'.
 Port COM1 is definded as default.
 Anemometer should be firstly configurated with HyperTerminal.
******************************************************************


 NUMBER OF MEASUREMENTS DESIRED: 10

     U      V      Z
   0.00   0.00   0.02
     U      V      Z
  -0.04  -0.18   0.11
     U      V      Z
  -0.02  -0.10   0.08
     U      V      Z
  -0.09   0.00   0.14
     U      V      Z
  -0.28  -0.18   0.09
     U      V      Z
  -0.20  -0.17   0.14
     U      V      Z
  -0.08  -0.08   0.10
     U      V      Z
  -0.16  -0.22   0.02
     U      V      Z
  -0.01  -0.05   0.05
     U      V      Z
   0.00   0.00   0.08



 DATA STORED IN: 'ultrasonic_data.txt'

 <PRESS ANY KEY TO EXIT...>_
```

Figure 55: Reading the data screenshot

All the screenshots shown have been from the .exe program. Once the wind has been measured, it is stored in a file called 'ultrasonic_data.txt`. The screenshot is shown next:



```
ultrasonic_data - Kladblok
Bestand  Bewerken  Opmaak  Beeld  Help

 DATE (dd/mm): 12/5

    U      V      Z
  0.00   0.00   0.02

    U      V      Z
 -0.04  -0.18   0.11

    U      V      Z
 -0.02  -0.10   0.08

    U      V      Z
 -0.09   0.00   0.14

    U      V      Z
 -0.28  -0.18   0.09

    U      V      Z
 -0.20  -0.17   0.14

    U      V      Z
 -0.08  -0.08   0.10

    U      V      Z
 -0.16  -0.22   0.02

    U      V      Z
 -0.01  -0.05   0.05

    U      V      Z
  0.00   0.00   0.08
```

Figure 56: 'ultrasonic_data.txt' screenshot

Chapter 11. CONCLUSIONS AND RECOMMENDATIONS

This section includes the final conclusions and the corresponding recommendations:

1.- The sensor built fulfils the desired goals.

It works autonomously, collects the data, is movable and it is simple and inexpensive.

2.- The accuracy of the propeller anemometers purchased was reduced by more than 5%.

When the propeller anemometers, Windlogs, were first calibrated in the wind tunnel, their error measurements were up to 10%. Therefore, an agreement to work with the manufacturers to improve their product was beneficial for both parties. This collaboration between the company and myself resulted in an improved product for the company and a more accurate sensor for this project.

After some tests and a new firmware version installed in the anemometers, the error was reduced to 3-4%. Therefore, as the low cost anemometer will always measure a lower wind speed, the corresponding error (3-4%) has to be added in order to obtain the real wind speed.

3.- Measurements corresponding to the horizontal plane are more accurate than those for the vertical component of the wind.

The 3D low-cost anemometer was tested on a roof of the EhB, together with the ultrasonic anemometer. The maximum error measured by the low-cost anemometer at low wind speeds was ±1m/s at the vertical component, and 0,6m/s on the horizontal plane.

This difference may be due to the fact that the shaft of one anemometer is placed horizontally and these devices may not be suitable to work in that position. Another possible cause could be that a balance weight was installed, in order to correct the balance of the anemometer, and this might have disturbed the measurements.

4.- At low wind speeds, the propeller anemometer also has a low resolution.

In the calibration process and in the comparison made between the 3D low-cost anemometer and the ultrasonic sensor, the errors at higher speeds were smaller. The reason for larger errors at low speeds is that the Windlogs get one count for every revolution of the anemometer. Given that at low speed there are less counts, that correlates with a lower resolution of wind speed.

5.- The development of a program to log the wind speed data from the ultrasonic anemometer eliminates the need for an expensive data logger.

While the propeller anemometer collects the data with a Windows Software, a program was developed to log and store the wind speed data from the ultrasonic anemometer. At the beginning, the possibility of buying an expensive data logger was considered, but this need was eliminated with the newly created program.

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Chapter 13. APPENDIX


Ready to harness the *wind*?
Test your location for wind viability with the new *WindLog™*
The WindLog™ is a compact, inexpensive wind data logger designed to test the wind viability of a location prior to the installation of a wind turbine. While many people rely on wind maps to assist them with this purchase decision, these maps do not provide detailed information for a specific area. The WindLog™ allows you to do your own accurate wind study to optimize your turbine placement and its performance. Install it on the prospective land or building to collect data on wind speed, wind gusts, and wind direction in real time.
NORTH
WindLog™
RainWise Inc.
RainWise® Inc.

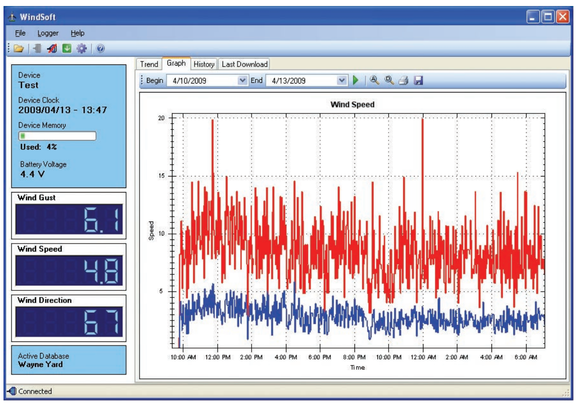
The WindLog™ features include:

- 1 MB of Flash memory stores over a years worth of wind data
- Operates on three AA Alkaline or Lithium batteries
- Uses USB power when connected to a computer
- USB port provides fast downloads
- Free Windows software
- Logs average speed, wind gust and average direction
- User selectable logging intervals from one minute to one hour

Data can be downloaded from the WindLog™ using a 15-foot USB cable and the no-cost Windows-based WindLogger™ software (WindSoft), which uses a SQLite database to track and record wind information. The logging interval can be set from once a minute to once an hour. USB extenders can be used to lengthen the USB cable to over 100 feet. The USB cable can be left connected to the WindLog™ allowing real-time viewing of the wind data on a computer. By combining both logged and real-time data WindLog can be used both online and offline. WindSoft can generate statistics, graphs and reports. It can also export CSV files for use with Microsoft Excel or any other application that supports CSV files.

Battery life for the logger will depend upon the environment and logging rates. Typical battery life is 6-9 months. When connected to a computer the WindLog™ will use the USB port power to run. This further extends the life of the batteries.

The Mini-Aervane wind sensor is equipped with low friction race bearings. This reduces the threshold to approximately one mile per hour. The wind direction sensor has a 16-point resolution. Logged direction readings are averaged readings.



A support mast is included with the WindLog™. This mast can be used with the Rainwise® Mono Mount or tripod. The mast may also be attached to a support structure using U-Bolts or lag screws.

Warranty Information

The WindLog™ has a 2-year warranty.

RainWise, Inc., is a manufacturer of weather monitoring systems for many industrial uses, including a line of HazMat products used by emergency service professionals. In business since 1974, RainWise is an employee-owned and operated company providing affordably-priced, high-quality products that are manufactured in the U.S. We are committed to providing outstanding customer service. We provide full technical and installation support for all of our products. Call us with any questions or problems. We also have our product showroom in Bar Harbor, Maine, to demonstrate our complete line of consumer products in person.

RainWise, Inc.
25 Federal Street
Bar Harbor, ME 04609
U.S.A.

GSA Schedule
Contract GS-07F-5342R

Product Specifications

SPEED
Range: 0 – 67 meters per second (150 Mph)
Accuracy: +/- 2%
Sensor: 4-blade propeller – Lexan – UV inhibited
Threshold: .45m/sec. (1 Mph)
Transducer: Magnetic dry reed switch
Frequency: 1 cycle per revolution

DIRECTION
Range: 360° – no deadband
Resolution: 22.5°, averaged.
Accuracy: +/- 22.5°
Sensor: Balanced vane with a 16.5cm (6.6 inch) radius
Threshold: .9 m/sec. (2 mph) at a 10° deflection.
The balanced propeller is supported in stainless steel instrument ball bearings.
The direction is obtained through 8 dry reed switches with no dead band.
The M-AV sensor is made from UV inhibited Dupont Delrin, Lexan and stainless steel.

RainWise® Inc.
800 762 5723
www.rainwise.com

MODEL 81000

ULTRASONIC ANEMOMETER

CE REV C031405

MANUAL PN 81000-90

R. M. YOUNG COMPANY

2801 AERO PARK DRIVE, TRAVERSE CITY, MICHIGAN 49686, U S A
TEL: (231) 946-3980 FAX: (231) 946-4772

WARRANTY AND ASSISTANCE

R.M. YOUNG PRODUCTS are warranted by CAMPBELL SCIENTIFIC (CANADA) CORP. ("CSC") to be free from defects in materials and workmanship under normal use and service for **twelve (12) months** from date of shipment unless specified otherwise. ***** **Batteries are not warranted.** ***** CSC's obligation under this warranty is limited to repairing or replacing (at CSC's option) defective products. The customer shall assume all costs of removing, reinstalling, and shipping defective products to CSC. CSC will return such products by surface carrier prepaid. This warranty shall not apply to any CSC products which have been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. This warranty is in lieu of all other warranties, expressed or implied, including warranties of merchantability or fitness for a particular purpose. CSC is not liable for special, indirect, incidental, or consequential damages.

Products may not be returned without prior authorization. To obtain a Return Merchandise Authorization (RMA), contact CAMPBELL SCIENTIFIC (CANADA) CORP., at (780) 454-2505. An RMA number will be issued in order to facilitate Repair Personnel in identifying an instrument upon arrival. Please write this number clearly on the outside of the shipping container. Include description of symptoms and all pertinent details.

CAMPBELL SCIENTIFIC (CANADA) CORP. does not accept collect calls.

Non-warranty products returned for repair should be accompanied by a purchase order to cover repair costs.

CAMPBELLSCIENTIFIC
CANADA CORP.
11564 - 149 street - edmonton - alberta - T5M 1W7
tel 780.454.2505 fax 780.454.2655
www.campbellsci.ca

OPERATING INSTRUCTIONS

Model 81000 Ultrasonic Anemometer

Contents

MODEL 81000
ULTRASONIC ANEMOMETER

YOUNG

1.0 SPECIFICATION SUMMARY

WIND SPEED

Range:	0 to 40 m/s (0 to 90 mph)
Resolution:	0.01 m/s
Threshold:	0.01 m/s
Accuracy:	±1% rms ±0.05 m/s (0 to 30 m/s)
	±3% rms (30 to 40 m/s)

WIND DIRECTION

Azimuth Range:	0.0 to 359.9 degrees
Elevation Range:	±60.0 degrees
Resolution:	0.1 degree
Accuracy:	±2° (1 to 30 m/s)
	±5° (30 to 40 m/s)

SPEED OF SOUND

Range:	300 to 360 m/s
Resolution:	0.01 m/s
Accuracy:	±0.1% rms ±0.05 m/s (0 to 30 m/s wind)

SONIC TEMPERATURE

Range:	-50 to +50 ºC
Resolution:	0.01 ºC
Accuracy:	± 2 ºC (0 to 30 m/s wind)

VOLTAGE OUTPUT (4 CHANNELS)

Range:	0 to 5000 mV
Resolution:	12 Bit
Accuracy:	± 0.1% of full scale

GENERAL

Air sample column:	10 cm high X 10 cm diameter
Air sample path:	15 cm
Output rate:	4 to 32 Hz (selectable)
Output formats:	Serial data (selectable)
	RS-232 and RS-485
Baud Rates:	1200 to 38400
Power Supply:	12 to 24 VDC, 110 mA
Dimensions:	Overall height 56 cm
	Support arm radius 17 cm
	Mounting 34 mm (1.34 in) diameter (standard 1 inch pipe)
Weight:	Sensor weight 1.7 kg (3.8 lb)

2.0 INTRODUCTION

The Young Model 81000 measures three dimensional wind velocity and speed of sound based on the transit time of ultrasonic acoustic signals. Sonic temperature is derived from speed of sound which is corrected for crosswind effects.

Measurement data are available as serial output using RS-232 or RS-485 connections. A variety of serial output formats are available including a custom format which is easily set by the user. Four voltage output channels representing sonic temperature and wind in either Cartesian or Polar coordinates are also provided.

Operating parameters may be edited via simplified menus using an ordinary serial communication program like HyperTerm. All parameters are stored in non-volatile memory.

Superior environmental resistance is achieved by using UV stabilized thermoplastic, stainless steel, and anodized aluminum components. Electrical connections are made via an easily accessible junction box. The unit mounts on standard 1 inch pipe, outside diameter 34mm (1.34").

3.0 INITIAL CHECKOUT

Carefully unpack the unit and inspect for physical damage. Any damage should be reported to the shipper. The 81000 arrives fully calibrated and ready to use.

FACTORY DEFAULT CONFIGURATION:

Serial Output:
- RS232 @ 38400 Baud
- ASCII Text Serial String
  - Wind Speed - 3D (m/s)
  - Direction (Deg)
  - Elevation (Deg)
  - Speed of Sound (m/s)
  - Sonic Temperature (°C)

Analog Voltage Outputs:
- Channel V1: Wind Speed (3D)
  0-5000 mV = 0-50 m/s
- Channel V2: Wind Direction
  0-5000mV = 0-540 Deg
- Channel V3: Elevation
  0-5000mV = -60° to +60°
- Channel V4: Sonic Temperature
  0-5000mV = 220K to 320K

A simple four-step operational check may be performed as follows:

1. Remove junction box cover. Connect power and signal wires to terminals as indicated in wiring diagram (on page 6) for RS-232 OUTPUT. Connect serial cable to computer COM port.

2. Start a serial communications program (like HyperTerm) with baud rate at 38400 and flow control set to NONE.

3. Apply power to the 81000 sensor. There will be a 4 second delay for initialization then the unit will begin to output data at four times per second using the following format: speed (m/s) azimuth (deg) elevation (deg) speed-of-sound (m/s) sonic-temperature (°C). Verify that all values are present on the display. Typical output is shown below:

```
0.00    0.0    0.0 346.70    25.14
```

```
0.00    0.0    0.0 346.68    25.11
0.00    0.0    0.0 346.76    25.25
0.00    0.0    0.0 346.80    25.30
0.00    0.0    0.0 346.76    25.25
0.00    0.0    0.0 346.80    25.30
0.00    0.0    0.0 346.80    25.30
0.00    0.0    0.0 346.82    25.35
```

A threshold level of 0.2 m/s is preset from the factory. Wind below the threshold, such as in still air, is output as 0.00 m/s. Azimuth may be any value from 0.0 to 359.9 degrees. When wind speed is below threshold level, azimuth output is maintained at the last value read before the wind speed went below threshold. Elevation remains zero until threshold is exceeded. Speed of sound ranges from 300 m/s to 360 m/s depending on temperature. At 20°C the value is about 344 m/s. Sonic temperature may be compared to a standard Celsius thermometer and should agree within ±2°C. If values appear questionable or any value is not displayed, remove power and check all wiring connections. If the problem cannot be corrected, contact your YOUNG representative.

4. Verify sensor response by gently blowing through the measuring section. Wind from the north side (marked "N"), should produce a positive SPEED response and an AZIMUTH display corresponding to North (i.e.: values around 359.9 or 0.0). Wind from the opposite direction should produce values indicating south, (around 180.0) and so forth. Downward wind produces negative ELEVATION values, upward wind produces positive values.

After proper operation is confirmed, the sensor may be installed. Complex data collection or serial communication schemes should be tested and verified before final installation. It is easier to confirm wiring connections and communication protocol on a test bench than a tower. Factory settings may be changed by following the instructions in the next section.

4.0 COMMAND MENU

Sending the ESC character (ASCII 27) three times in quick succession takes the unit out of OPERATE mode and causes the COMMAND MENU to appear.

```
COMMANDS (VERSION 6.6.07)
------------------------
R) REPORT
S) SETUP
X) EXIT TO OPERATE MODE
```

Access each menu item by sending the character associated with the menu item of interest. Characters may be upper or lower case. Send "X" to return to OPERATE mode. The following paragraphs explain the function of each menu item and associated sub-menu. The version number may differ from that shown above.

5.0 REPORT

REPORT summarizes current parameter settings. Some parameters are for factory diagnostics only and cannot be accessed or altered by the user. Typical values appear below.

```
PATH  LENGTH(cm) CH  DELAY(uS) CMP
----------------------------------
A     15.341    1   19.650    516
                4   19.550    484
B     15.245    2   23.875    570
                5   23.750    524
C     15.146    3   26.675    511
                6   26.500    466

           OUTPUT FORMAT: CUSTOM
 789AB [ 3D-SPEED AZIMUTH ELEVATION SOS Ts ]
        WIND SPEED UNITS: m/s
             OUTPUT RATE: 4 Hz
     SAMPLES FOR AVERAGE: 0
                    MODE: AUTO
         WAKE CORRECTION: YES
          ERROR HANDLING: OMIT INVALID DATA
   VOLTAGE OUTPUT FORMAT: SPEED, AZIMUTH, ELEVATION, TEMP
    VOLTAGE OUTPUT SCALE: 0 TO 25 m/s = 0-5000 mV
                          0 TO 540 DEG AZIMUTH = 0-5000mV
                          -60 TO +60 DEG ELEVATION = 0-5000 mV
                          220K to 320 K DEG KELVIN = 0-5000mV
   CORRELATION TOLERANCE: 125
           COMPARE SHIFT: 0
    HI SPEED ADC SAMPLES: 10
               THRESHOLD: 20 cm/s
            ACCESS LEVEL: NORMAL
```

6.0 SETUP

SETUP allows editing operating parameters to suit the needs of a particular application. The SETUP menu and detailed explanation of each menu item follows:

```
SET PARAMETERS
------------------------
A) AVERAGING
B) BAUD
E) ERROR HANDLING
N) SCALING MULT
O) OUTPUT RATE
P) POLL CHARACTER (ADDR)
S) SER OUT FORMAT
T) THRESHOLD
U) UNITS
V) V OUT FORMAT
W) WAKE CORRECTION
X) EXIT TO MAIN MENU
```

6.1 AVERAGING

AVERAGING sets the number of output samples used to calculate block averages of all measurements including voltage inputs.

For no averaging, set NUMBER OF SAMPLES TO AVERAGE to 0. Otherwise, set it to the number of output samples to be used for calculating the block average. The rate at which block averages are output is determined by OUTPUT RATE and NUMBER OF SAMPLES TO AVERAGE parameters. For example, if OUTPUT RATE is 4 Hz and NUMBER OF SAMPLES TO AVERAGE is 8, the unit will produce a block average output once every 2 seconds (0.5 Hz).

$$\frac{4 \text{ samples}}{\text{second}} \times \frac{1 \text{ avg result}}{8 \text{ samples}} = \frac{1 \text{ avg result}}{2 \text{ seconds}}$$

```
NUMBER OF SAMPLES TO AVERAGE:  0
   ENTER NEW VALUE (0 - 320):
```

6.2 BAUD RATE

BAUD sets the baud rate for serial communication. Faster baud rates may be required if the output string is long and the output rate is fast (see OUTPUT RATE). There is also a setting for HALF or FULL duplex RS-485. HALF duplex may be used in simple installations where minimal wiring is required and the unit is set for continous output. Use FULL duplex when polling or frequent parameter changes are anticipated. Note that the DUPLEX setting applies to RS-485 only since the RS-232 is always full duplex by default.

```
BAUD: 38400
---------------------
A) 1200
B) 2400
C) 4800
D) 9600
E) 19200
F) 38400
X) EXIT TO MAIN MENU

FOR RS-485 ONLY!
DUPLEX = 2
----------------------
1) HALF
2) FULL
X) EXIT TO MAIN MENU
```

6.3 ERROR HANDLING

ERROR HANDLING determines the manner in which invalid measurements are handled. Invalid measurements can occur when the acoustic path of the sonic signal is blocked or internal circuits fail. Acoustic blockage may be caused by rain drops, ice, snow, or other debris. When set to INCLUDE INVALID DATA, an output always occurs. If CUSTOM serial output is used, an ERROR CODE may be included in the output string to indicate an error condition. When set to OMIT INVALID DATA, invalid measurements are not output.

```
ERROR HANDLING: 2
-----------------
1) INCLUDE INVALID DATA
2) OMIT INVALID DATA
X) EXIT
```

6.4 SCALING MULTIPLIER

SCALING MULT sets overall scaling for UVW, 2D, and 3D wind speed outputs. Azimuth and elevation angle are not effected. The default value of 10000 represents a scaling multiplier of 1.0000. Normally, this value should not be changed since each instrument is calibrated in the YOUNG factory wind tunnel. Users who wish to alter the scaling based on independent calibration assessment may use this parameter to do so.

```
SCALING MULTIPLIER: 10000
   ENTER NEW VALUE:
```

6.5 OUTPUT RATE

OUTPUT RATE sets the rate at which samples serially output. Fast output rates and long serial output strings may require higher baud rates in order to keep up with the outgoing data stream. See SERIAL COMMUNICATION in SECTION 7 for additional details. If AVERAGING is used, average results are available only after enough output samples have been collected. See AVERAGING for details.

```
OUTPUT RATE 4Hz
--------------------
A) 4 HZ
B) 5 HZ
C) 8 HZ
D) 10 HZ
E) 16 HZ
F) 20 HZ
G) 32 HZ
X) EXIT TO MAIN MENU
```

6.6 POLL CHARACTER

POLL CHARACTER (ADDR) sets the address character for polled operation (POLL CUSTOM or POLLED BINARY output formats). Any printable ASCII character may be used to assign an address that uniquely identifies the instrument. When bussed on an RS-485 network with other 81000 instruments, each one should have a different address character.

```
POLL CHARACTER (ADDR): A
  ENTER NEW CHARACTER:
```

To poll the 81000, send MA! where A is the unique POLL CHARACTER. The 81000 will respond with the POLL CHARACTER and a space followed by the serial output string.

6.7 SERIAL OUTPUT FORMAT

SERIAL OUTPUT FORMAT sets the output string for serial output. Preset and custom formats are available.

```
SERIAL OUTPUT FORMAT 1
-----------------------------------
1) CUSTOM
2) RMYT (CHANGES OTHER PARAMETERS, SEE MANUAL)
3) NMEA (CHANGES OTHER PARAMETERS, SEE MANUAL)
4) POLL CUSTOM
5) BINARY
6) POLL BINARY
X) EXIT TO MAIN MENU
```

6.7.1 CUSTOM

CUSTOM format allows the user to construct an ASCII-printable serial output string. Long strings may require higher BAUD rates or lower OUTPUT RATES. (See BAUD and OUTPUT RATE.) Also, see UNITS. When CUSTOM is selected the following message and submenu appear:

```
CURRENT SERIAL OUTPUT FORMAT:
789AB [ 3D-SPEED AZIMUTH ELEVATION SOS Ts ]
CONSTRUCT AN OUTPUT FORMAT BY SELECTING FROM THE LIST BELOW.
ELEMENTS MAY BE IN ANY ORDER. REFER TO MANUAL FOR DETAILS.
-------------------------------------------------------
5) UVW
6) 2D SPEED
7) 3D SPEED
8) AZIMUTH
9) ELEVATION
A) SOS
B) Ts
E) ERR CODE
V) INTERNAL VOLTAGE

ENTER CUSTOM STRING (12 CHARACTERS MAX):
```

UVW is the orthogonal u, v, and w wind velocities. All three values are output. Typically the 81000 is oriented with u-axis aligned east-west and v-axis aligned north-south. In this orientation, +u values = wind from the east; +v values = wind from the north. Wind from below (updraft) = +w. Refer to ORIENTATION KEY drawing for illustration.

2D SPEED is wind magnitude in the u-v plane.

3D SPEED is wind magnitude in three dimensional space.

AZIMUTH is the 0.0-359.9° wind direction angle in the u-v plane. With the 81000V junction box facing south, 0.0° = north, 90.0° = east, 180.0° = south, and 270.0° = west. Refer to ORIENTATION KEY drawing for illustration.

ELEVATION is the ±90.0° wind elevation angle relative to the u-v plane. Values are positive when wind is from below (updraft) and negative when from above (downdraft). Effective elevation angle measurements are limited to ±60.0°. Refer to ORIENTATION KEY drawing for illustration.

SOS is the speed of sound.

Ts is the sonic temperature derived from SOS.

ERROR CODE indicates the validity of the measurement. Any non-zero value indicates an invalid measurement. ERROR HANDLING must be set to INCLUDE INVALID DATA to use this field. Keys to the error codes provide no useful information to the user.

INTERNAL VOLTAGE is the internal supply voltage. Because it is measured after current overload protection devices, it will always be less than the supply voltage measured at the connection terminals.

6.7.2 RMYT

RMYT sends wind speed and direction in a format suitable for use with the YOUNG Model 06201 Wind Tracker display unit. RS-485 outputs must be used. **When RMYT is selected the OUTPUT RATE is changed to 4 Hz, BAUD RATE is changed to 9600, and THRESHOLD is set to 10 cm/sec.**

6.7.3 NMEA

NMEA sends wind speed and direction in NMEA marine format to Young Model 06206 Marine Wind Tracker display or other NMEA device. The sentence is $WIMWV,aaa,R,ss.s,N,A where aaa = wind direction angle in degrees and ss.s = wind speed in knots. **When NMEA is selected the OUTPUT RATE is changed to 4 Hz and THRESHOLD is set to 10 cm/sec.** Most NMEA systems use 4800 baud but, because some systems use other baud rates, this setting should be changed manually if necessary.

6.7.4 POLL CUSTOM

POLL CUSTOM format allows the 81000 to be polled for an output. See CUSTOM for details on constructing the output string. Poll by sending MA! where A is the POLL CHARACTER ADDRESS. **Allow at least 5 milliseconds between each poll command character.** The 81000 responds with the POLL CHARACTER followed by the custom serial output string. Up to 32 sonic anemometers may be networked using the RS-485 connection. By assigning a unique address to each device, multiple units may run on the same network and respond individually only when polled.

6.7.5 BINARY

BINARY format sends serial output data in raw non-ASCII binary values. The advantage of using the BINARY output format is that data output string is shorter and the data does not have to be parsed and converted from ASCII. The disadvantage is that the output is non-textual so it cannot be examined directly using a simple serial communications program or other text based programs. The 12-byte binary output string description appears below.

Byte Index	Description
0	Hex 0xABCD header to identify start of string
2	Poll character ASCII code
3	Error code
4	U vector cm/s (signed integer)
6	V vector cm/s (signed integer)
8	W vector cm/s (signed integer)
10	T Sonic temperature K x 100 (unsigned integer)

6.7.6 POLLED BINARY

POLLED BINARY format sends serial output data in raw non-ASCII binary values in response to the standard MA! polling command. See the previous list for details on the BINARY output format.

6.8 THRESHOLD

THRESHOLD sets the wind speed threshold and applies only to the following output formats: NMEA, RMYT, SPEED AZIMUTH ELEVATION. UVW outputs are unaffected. Setting THRESHOLD greater than 0 prevents fluctuating azimuth and elevation values at wind speeds near zero. While these values are correctly derived, they are meaningless or distracting in some applications.

When speed is at or above threshold, output values are updated normally. When speed is below threshold, speed and elevation outputs are set to zero and the azimuth output is held at its last value. Setting THRESHOLD to 0 effectively disables the feature. Note that units are cm/sec.

```
                          THRESHOLD (cm/s) :20
ENTER NEW THRESHOLD (cm/s, 0-500) :
```

6.9 UNITS

UNITS sets wind speed units for CUSTOM serial output. Resolution associated temperature units are as follows:

Wind Speed units and resolution		Temperature units and resolution	
cm/s	1	K	0.01
m/s	0.01	C°	0.01
mph	0.1	F°	0.01
km/h	0.1	C°	0.01
knots	0.1	F°	0.01

```
UNITS 2
 -------------------
1) cm/s
2) m/s
3) mph
4) km/h
5) knots
X) EXIT TO MAIN MENU
```

6.10 VOLTAGE OUTPUT FORMAT

VOLTAGE OUTPUT FORMAT sets format, scaling and output range for voltage outputs. Only wind speed scaling may be set by the user. AZIMUTH, ELEVATION, and SONIC TEMPERATURE scaling is fixed. Full scale output range for all voltage outputs may be set to either 0-4000 or 0-5000 millivolts.

Choose format from the menu.

```
VOLTAGE OUTPUT FORMAT 2
 -----------------------
1)     U V W TEMP
2)     SPEED AZ ELEV TEMP
X)     EXIT
```

6.10.1 SCALING

If UVW format is chosen, the follwoing prompt is shown with current wind scale setting:

```
VOLTAGE OUTPUT SCALE: -25 TO 25 m/s
ENTER NEW VALUE (10-60):
```

You must enter a value for the scale. Note that with UVW format, the value you enter will be bipolar scale (ie: 25 means -25 to +25 m/s).

If SPEED AZIMUTH ELEVATION format is selected, the following prompt is shown with current wind scale setting:

```
VOLTAGE OUTPUT SCALE: 0 TO 50 m/s
ENTER NEW VALUE (10-60):
```

You must enter a value for the scale.

With SPEED AZIMUTH ELEVATION format, AZIMUTH scale is fixed at 0 to 540° and ELEVATION is fixed at -60° to +60°.

SONIC TEMPERATURE scale is always 220 °K to 320°K.

6.10.2 RANGE

After setting the scale, the current setting for output range is shown along with a menu for changing it.

```
VOLTAGE OUTPUT FULL SCALE = 5
 ----------------------------
4) 4000 mV
5) 5000 mV
X) EXIT
```

The 5000 millivolt (mV) output range (default) is recommended for all new installations. The 4000 mV range is available to compatible with earlier models already installed.

6.10.3 CONVERSION TO ENGINEERING UNITS

The range applies to all voltage output channels. The following relationships may be used to interpret output values:

For UVW format:
U,V, or W windspeed = [(Scale x 2 / Range) x mV] - Scale
Example:
W channel output value = 2550 mV
Scale = 25 m/s
Range = 5000 mV
SPEED = [(25 x 2 / 5000) x 2550] -25 = 0.5 m/s

For SPEED AZIMUTH ELEVATION Format:
Windspeed = [(Scale / Range) x mV]
Example:
SPEED channel output value = 1950 mV
Scale = 25 m/s
Range = 5000 mV
Speed = [(25 / 5000) x 1950] = 9.75 m/s

Azimuth = [(540 / Range) x mV]
Example:
AZIMUTH channel output value = 4250 mV
Range = 5000 mV
Azimuth = [(540 / 5000) x 4250] = 459°
If the result is greater that 360, subtract 360.
Azimuth = (459 - 360) = 99°

Elevation Angle = [(120 / Range) x mV] -60
Example:
ELEVATION channel output value = 2200 mV
Range = 5000 mV
Elevation Angle = [(120 / 5000) x 2200] - 60 = -7.2°

Voltage output scale for sonic temperature is fixed and depends only on the temperature voltage output value and selected range.

Temperature = [(100 / Range) x mV] +220
Example:
TEMPERATURE channel output value = 3780 mV
Range = 5000 mV
Temp °K = [(100 / 5000) x 3780] +220 = 295.6 °K
To convert to °C, subtract 273.15.
295.6 - 273.15 = 22.45 °C

When ERROR HANDLING is set to INCLUDE INVALID DATA, the voltage output channels go to positive full scale when an invalid measurement occurs. When set to OMIT INVALID DATA, the voltage output remains at the last valid value until a new valid measurement occurs.

IMPORTANT:
For VOLTAGE OUTPUTS to function properly, the 81000 serial output must be set to CUSTOM format.

6.11 WAKE CORRECTIONS

WAKE CORRECTION enables or disables real-time correction algorithms. To compensate for flow distortions in the wake of support struts and other mechanical features, each 81000 is individually calibrated in the YOUNG factory wind tunnel (NIST traceable) to generate a unique correction table which is stored in the unit. Additional compensating algorithms correct for elevation angle distortions and crosswind effects on speed of sound.

```
            WAKE CORRECTION: YES
USE WAKE CORRECTION? (Y/N):
```

7.0 APPLICATION NOTES

SERIAL COMMUNICATION
Selection of RS232 or RS485 is made inside the sensor j-box by positioning the shorting blocks on jumper W3. Typical wiring connections are shown on page 6. RS-485 half-duplex connections can simplify some installations since less cable is needed and, when operated in polled mode, the connections may be bussed.

Long custom output strings at high output rates and low baud rates may exceed the time needed to send the string. Solutions include using fewer measurement parameters, lower OUTPUT RATES, higher BAUD RATE, or some combination of these solutions. With measurement parameters, for example, sending wind data in both UVW and SPEED, AZIMUTH, ELEVATION formats is redundant and wastes space in the string.

HALF DUPLEX TIMING CONSTRAINTS
If RS-485 half-duplex mode is used for continuous output, high output rates and long output strings create a progressively smaller window of time in which to receive commands. Under some conditions, the 81000 may not respond to the ESC commands since the unit will be spending most of its time in transmit mode. RS-485 is best used in POLLED MODE or at modest output rates. In contrast, a full-duplex RS-232 or RS-485 scheme is immune to the timing limitations described above and commands may be received even while data is being sent.
Polling in half-duplex RS-485 mode at high rates may be limited by the timing capability of both the polling device and the 81000. Advantages gained from bussing multiple sensors may be lost if timing problems arise. For fast polling, a full-duplex scheme is recommended.

When polling allow at least 5 milliseconds between polling characters. Do not exceed 1000 milliseconds between characters.

HIGH WIND SPEED MEASUREMENTS
For best measurement results, particularly at high wind speeds,

always choose the lowest OUTPUT RATE possible. Lower output rates use a greater number of internal samples to generate the result and are more immune to outliers in the samples. If measuring for spectral content, carefully determine the needed sampling rate and use the lowest OUTPUT RATE necessary.

RAIN AND SNOW
Anything that blocks the acoustic signal path will degrade the measurement. If the path is blocked sufficiently, measurements cannot be made. The 81000 can make accurate measurements in driving rain even at high OUTPUT RATES but light mist or heavy fog can allow droplets to accumulate on the transducer faces and block the measurement.

Measurements may be made in driving snow although frost and snow that adheres to the transducer face may block the measurement. Similarly, freezing rain on the transducer face may block the measurement.

POWER CONNECTIONS
Supply power must be in the range of 12 to 24 VDC **at the sensor junction box terminals** in order for the sensor to operate properly. For long cables, be sure to allow for voltage drop due to wire resistance.

8.0 WARRANTY

This product is warranted to be free of defects in materials and construction for a period of 12 months from date of initial purchase. Liability is limited to repair or replacement of defective item. A copy of the warranty policy may be obtained from R. M. Young Company.

9.0 CE COMPLIANCE

This product has been tested and shown to comply with European CE requirements for the EMC Directive. Note that shielded cable must be used.

Declaration of Conformity

Standards to which Conformity is Declared:
EN 55022 Group 1 (CISPR 22 class B)
EN 50082-1:1997 using
EN61000-4-2:1995
EN61000-4-3:1995 with ENV50204: 1995
EN61000-4-4:1995
EN61000-4-6:1995

Manufacturer's Name and Address:
R. M. Young Company
Traverse City, MI, 49686, USA

Importer's Name and Address:
See Shipper or Invoice

Type of Equipment:
Meteorological Instruments

Model Number / Year of Manufacture:
81000/2000

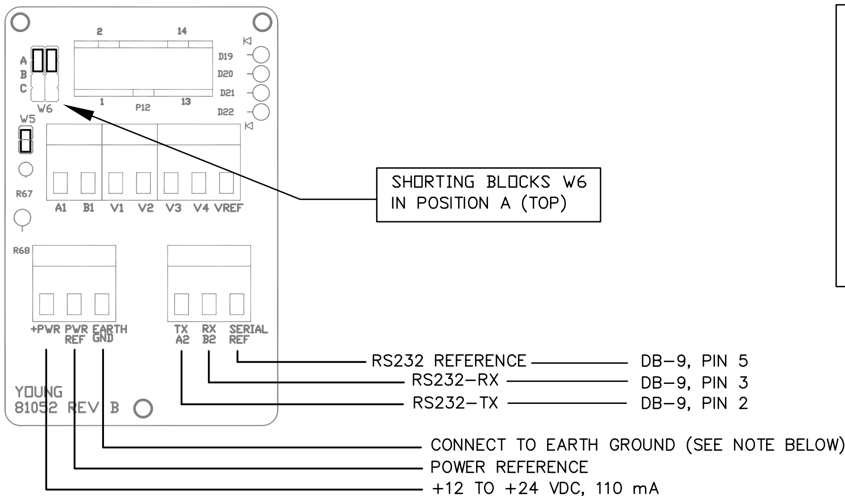
I, the undersigned, hereby declare that the equipment specified conforms to the above Directives and Standards.

Date / Place:
Traverse City, Michigan, USA May 1, 2000

David Poinsett
R & D Manager, R. M. Young Company

MODEL 81000 ULTRASONIC ANEMOMETER – WIRING CONNECTIONS

RS–232



GENERAL NOTES

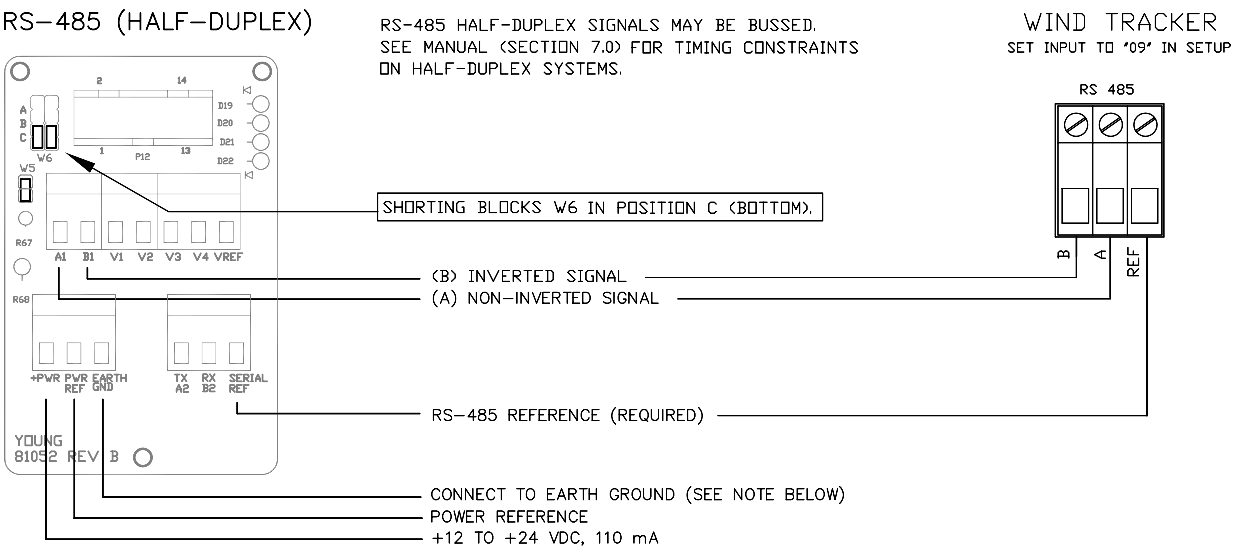
ALL SERIAL COMMUNICATIONS USE THE FOLLOWING SETTINGS:

1 START
8 DATA
NO PARITY
1 STOP
NO FLOW CONTROL
BAUD RATE SET BY USER

SHORTING BLOCKS ON W6 MUST BE IN POSITION SHOWN.

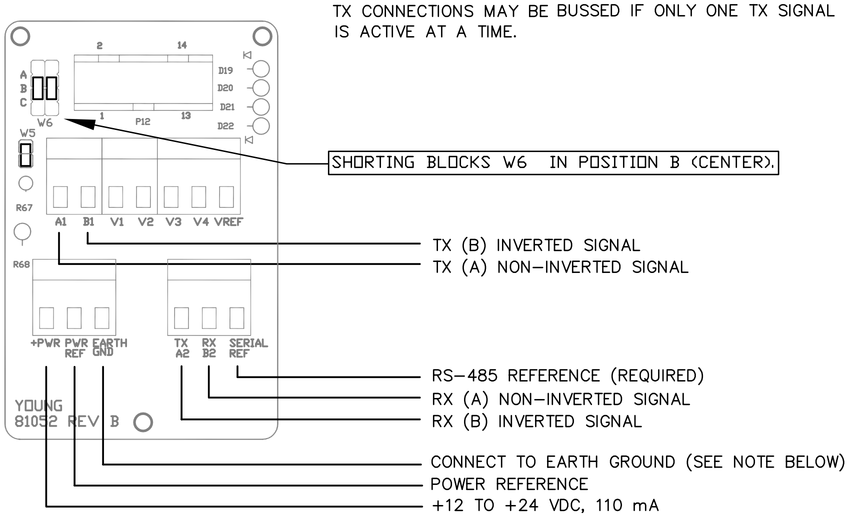
RS–485 (HALF–DUPLEX)

RS–485 HALF–DUPLEX SIGNALS MAY BE BUSSED. SEE MANUAL (SECTION 7.0) FOR TIMING CONSTRAINTS ON HALF–DUPLEX SYSTEMS.



RS–485 (FULL–DUPLEX)

FULL DUPLEX RS–485 RX CONNECTIONS MAY BE BUSSED. TX CONNECTIONS MAY BE BUSSED IF ONLY ONE TX SIGNAL IS ACTIVE AT A TIME.

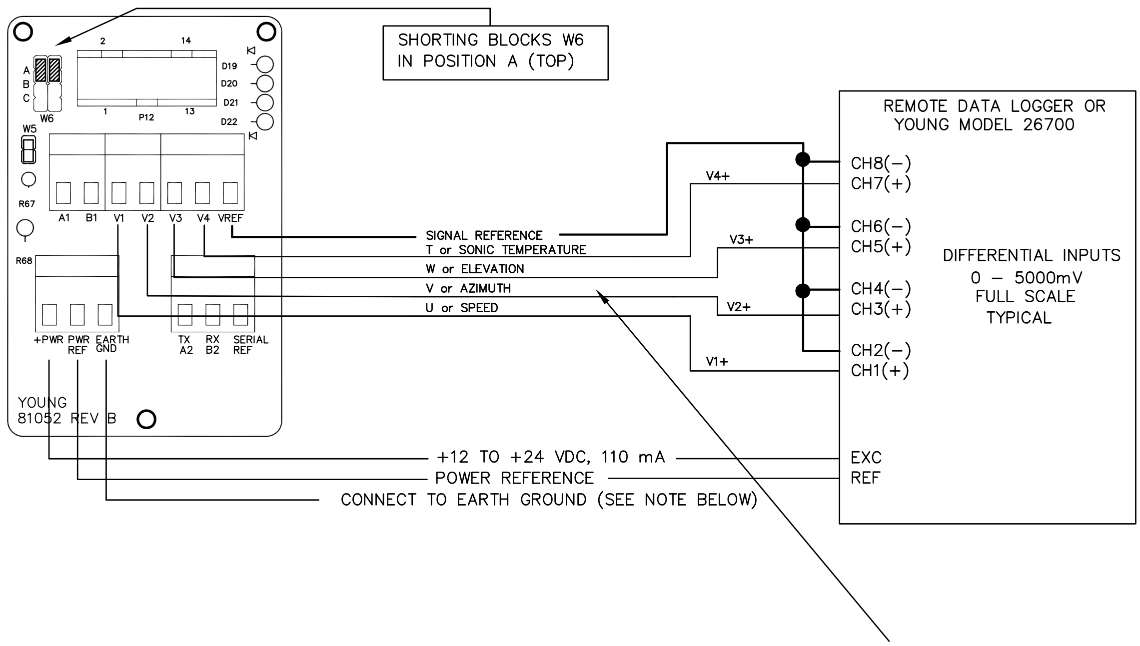


EARTH GROUND CONNECTION

EARTH GROUND CONNECTION MUST BE USED. FAILURE TO USE EARTH GROUND CONNECTION MAY RESULT IN DAMAGE TO THE SENSOR.

MODEL 81000 ULTRASONIC ANEMOMETER – WIRING CONNECTIONS

VOLTAGE OUTPUT

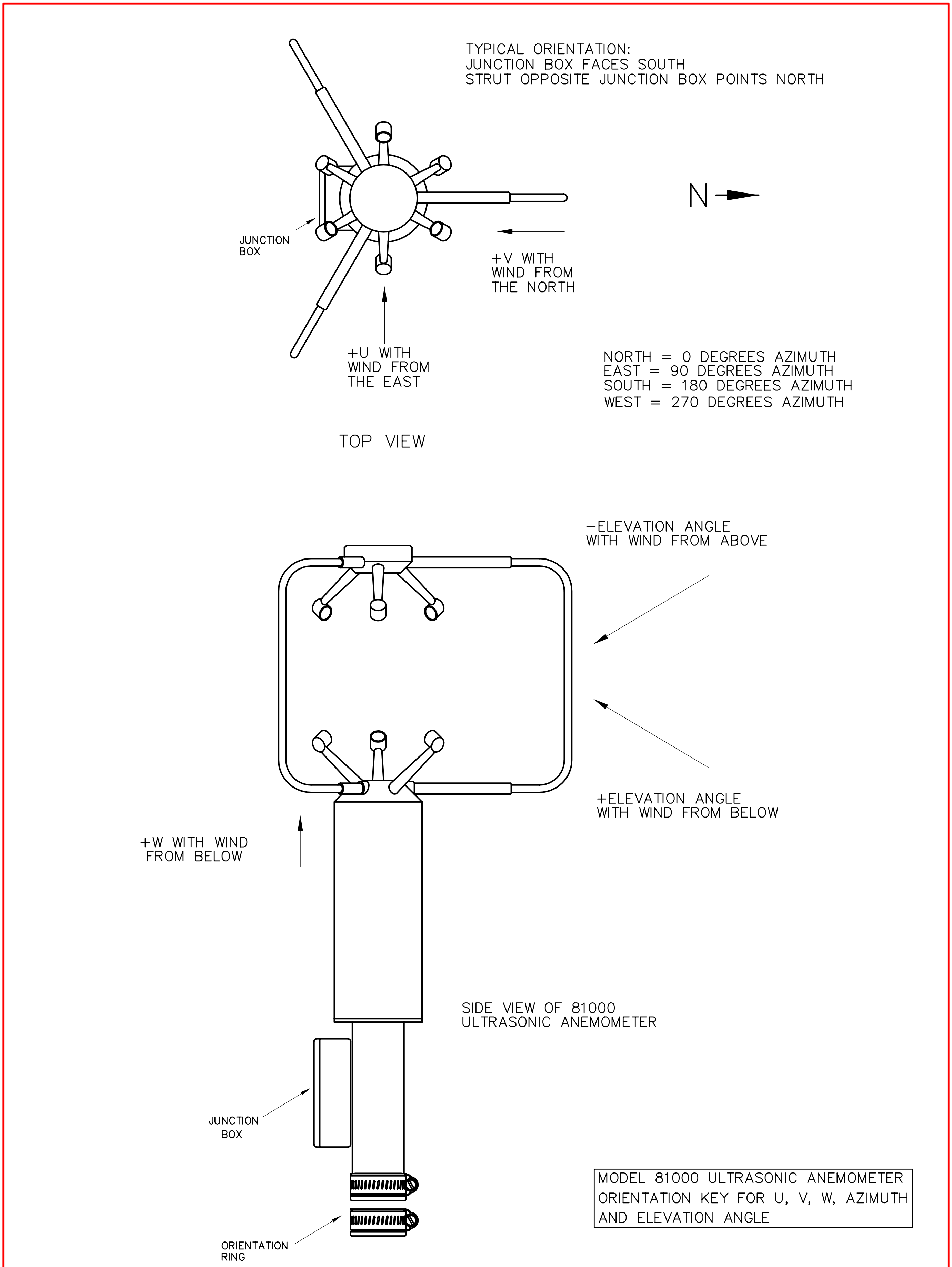


VOLTAGE OUTPUTS		
CH	FORMAT 1	FORMAT 2
V1	U	SPEED
V2	V	AZIMUTH
V3	W	ELEVATION
V4	SONIC TEMPERATURE	

VOLTAGE OUTPUT SCALE	
0–4000mV	0–5000mV

EARTH GROUND CONNECTION

EARTH GROUND CONNECTION MUST BE USED. FAILURE TO USE EARTH GROUND CONNECTION MAY RESULT IN DAMAGE TO THE SENSOR.



TYPICAL ORIENTATION:
JUNCTION BOX FACES SOUTH
STRUT OPPOSITE JUNCTION BOX POINTS NORTH
N
JUNCTION BOX
+V WITH WIND FROM THE NORTH
+U WITH WIND FROM THE EAST
NORTH = 0 DEGREES AZIMUTH
EAST = 90 DEGREES AZIMUTH
SOUTH = 180 DEGREES AZIMUTH
WEST = 270 DEGREES AZIMUTH
TOP VIEW
−ELEVATION ANGLE WITH WIND FROM ABOVE
+ELEVATION ANGLE WITH WIND FROM BELOW
+W WITH WIND FROM BELOW
SIDE VIEW OF 81000 ULTRASONIC ANEMOMETER
JUNCTION BOX
ORIENTATION RING
MODEL 81000 ULTRASONIC ANEMOMETER
ORIENTATION KEY FOR U, V, W, AZIMUTH
AND ELEVATION ANGLE